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Use of Insulation for Frost Prevention
Jackman Airport, Maine, 1986—1987 Winter

Maureen A. Kestler and Richard L. Berg

January 1991

Cover: Installation of insulation at Newton Field, Jackman, Maine.

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U.S. Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

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Prepared for
U.S. DEPARTMENT OF TRANSPORTATON
FEDERAL AVIATION ADMINISTRATION
OFFICE OF THE CHIEF OF ENGINEERS

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PREFACE

This report was prepared by Maureen A. Kestler and Dr. Richard L. Berg, Research Civil Engineers, Civil and Geotechnical Engineering Research Branch, Experimental Engineering Division, U. S. Army Cold Regions Research and Engineering Laboratory. Funding for this study was primarily provided by the Federal Aviation Administration as part of the FAA-CRREL Interagency Agreement DTFA 01-84-2-02038. The USACE portion was funded through DA Project 4A762784AT42, *Design, Construction and Operations Technology for Cold Regions*; Task BS, *Base Support*; Work Unit 036, *Improved Pavement Design Criteria in Cold Regions*. This report was technically reviewed by Hisao Tomita (FAA) and Wendy Allen (CRREL).

The authors thank Richard Guyer for instrumentation installation and data collection, Marcia VanCamp for collecting data, Blair VanCamp for assisting in equipment installation, and Pamela Bosworth for typing the manuscript.

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CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM Metric *Practice Guide* (E 380-89a), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380-89a).

Multiply	*By*	*To obtain*
inch	25.4*	millimeter
foot	3.048*	meter
mile	1.609	kilometer
degree Fahrenheit	$(t_{°F}-32)/1.8$	degree Celsius

*Exact.

Use of Insulation for Frost Prevention
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MAUREEN A. KESTLER AND RICHARD L. BERG

INTRODUCTION

A 2-in.-thick layer of extruded polystyrene insulation was placed beneath the runway, taxiway and parking apron during the 1986 reconstruction of Newton Field in Jackman, Maine. The purpose of the study described here was twofold: 1) to evaluate the effectiveness of the insulation in preventing frost from penetrating beneath the insulation into the frost-susceptible subgrade, thus resulting in unacceptable frost heave, and 2) to compare performance with that of a nearby reconstructed roadway (Nichols Road) with a cross section similar to that proposed for the runway had no insulation been used. Articles in *New England Construction* and *Airport Services Management* discussed the Jackman Airport Construction Project (Fournier 1986, Davis and Johnson 1987).

LOCATION

Newton Field and Nichols Road are located within one mile of each other on the east side of U.S. Route 201 in the town of Jackman, Maine (45°38', 70°15'). This town is situated in a valley within the Moose River Watershed of northwestern Maine. The runway elevation is approximately 1175 ft above MSL; the 100-year flood level of the nearby Moose River is approximately 1170 ft (Fig. 1 and 2).

WEATHER DATA

Although weather data from Jackman are limited, a full range of data is provided by the town of Madison, Maine, located approximately 70 miles south-southeast of Jackman. From 1951 through 1980, Madison's air freezing index averaged 1366°F-days with a maximum of 1878°F-days (1970–1971 winter), a minimum of 767°F-days (1957–1958 winter), and design value (the average of the three coldest winters in the 30-year period) of 1795°F-days. Weather data for Madison are shown in Table 1. Jackman's average annual temperature was 38.3°F from January 1980 through December 1985 (Table 2), and was 37.9°F over the past 30 years. The design freezing index at Jackman is approximately 2570°F-days.

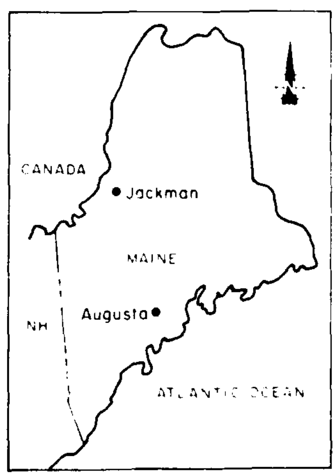
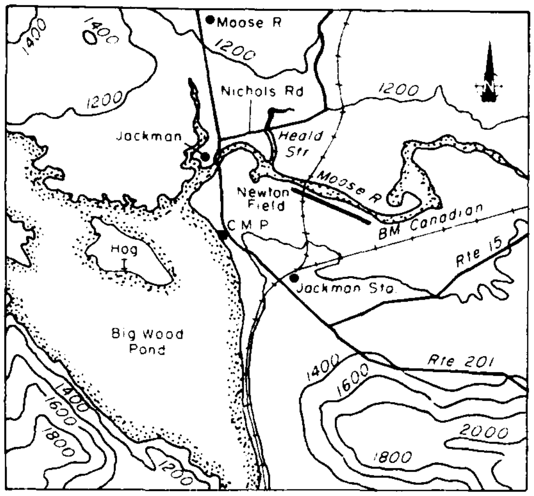
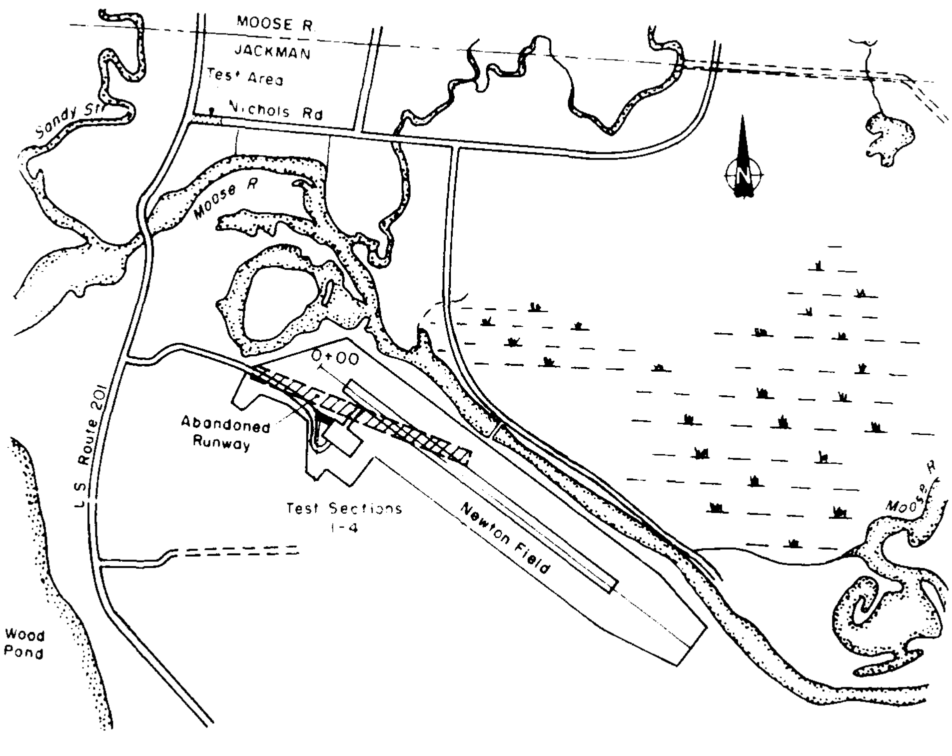


Figure 1. Location map.



a. Topographic map.



b. Map of study areas.

Figure 2. Vicinity maps, Jackman, Maine.

Table 1. Weather data for Madison, Maine: 1951–1980. (44°48', 69°53', elevation 260 ft)

Date	Avg daily max(°F)	Avg daily min(°F)	Avg daily (°F)	Avg heating D.D.(°F)	Avg thawing* D.D.(°F)	Avg freezing† D.D.(°F)
Jan	28	5	17	1499	0	476
Feb	31	6	18	1317	0	384
Mar	39	19	29	1116	11	104
Apr	52	30	41	718	272	0
May	66	40	53	378	645	0
Jun	75	50	62	81	909	0
Jul	80	55	68	3	1102	0
Aug	78	53	66	17	1040	0
Sep	70	45	57	227	764	0
Oct	58	36	47	559	464	0
Nov	45	27	36	877	113	0
Dec	31	12	21	1351	0	328
Year	54	32	43	8111	5320	1293

*Thaw starts as early as 1 Mar 1958 and as late as 6 Apr 1964, but usually about 22 Mar. Length of thawing season averages 246 days and ranges from 223 to 282 days. The design length of the thawing season is 260 days.

†Freezing degree days (seasonal daily data): Avg 1366. Max 1878 (winter 1970-1971). Min 767 (winter 1957–1958). Design 1795. Freezing starts as early as 8 Nov 1971 and as late as 15 Dec 1953, but usually around 23 Nov. The length of the freezing season averages 119 days and ranges from 97 to 141 days.

SITE

Soil profiles for both Newton Field and Nichols Road are shown in Figures 3a and 3b, respectively. In 1970, a field investigation was conducted for the U.S. Route 201 Jackman–Moose River Project F-033-2(1). The following is an excerpt from the soils investigation report (Prue and Morgan 1970) for the segment of road corresponding to the starting station at Nichols Road:

> Auger borings, road soundings and backhoe test pits were used to determine soil types in this section. Fluvial deposits of highly frost-susceptible varved sandy clay silts and silty sands were found interbedded. Some nonfrost-susceptible clean sands were also found with this material at random locations and depths and usually with silt layers. The soil stratus were firm.
>
> The water table was at a relatively shallow depth in this plane.
>
> The existing road consists of approximately one foot of silty sandy fine gravel and pavement over one foot of pebbly sandy silt.
>
> Soils are firm and should adequately support the proposed embankments.
>
> The frost penetration in this area is severe...and highly frost-susceptible soils occur with slightly frost-susceptible or nonfrost-susceptible soils within the frost penetration zone.
>
> The water table is shallow in this area, and unless precautions are taken severe differential heaving could be expected in this section. The recently completed adjacent project in Jackman experienced severe heaving and consequential breaking of pavement the first winter after construction, even though some undercutting of subgrade was done.
>
> If this unacceptable frost damage is to be prevented or at least diminished one of two approaches might be considered, either a thick layer of granular material or insulation of the subgrade.

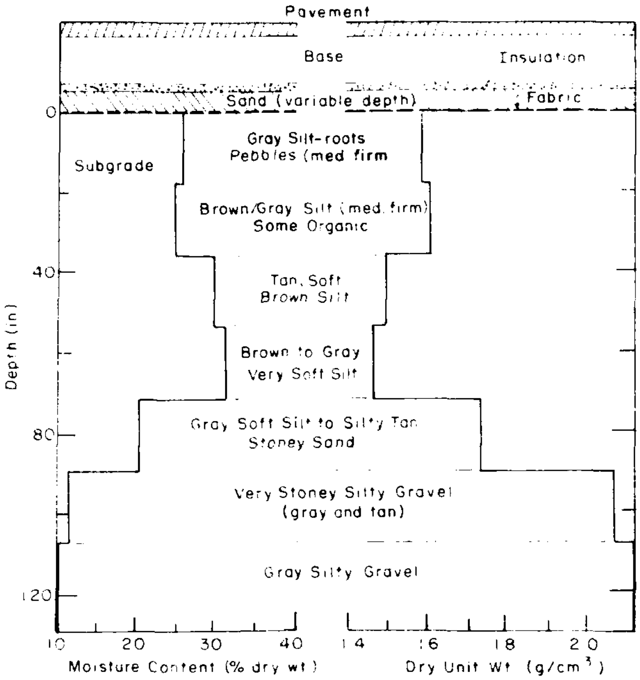
Table 2. Annual average air temperatures for Jackman and Madison.

Year	Madison ann avg (°F)	Madison dep (°F)	Jackman ann avg (°F)	Temp Dif M-J (°F)
1956	23.1	2.9	19.3	3.8
1957	44.2	2.3	40.1	4.1
1958	43.1	–0.4	39.1	4.0
1959	44.5		40.8	3.
1960	44.4	0.9	41.0	3.4
1961	44.2		41.0	3.2
1962	42.1		39.0	3.1
1963	43.3	–0.2		
1964	43.5	0.0	38.6	4.9
1965	43.0	–0.5	37.8	5.2
1966	44.2	0.7		
1967	42.2	–1.3	37.4	4.8
1968	41.6	–1.9	38.1	3.5
1969	42.3	–1.2	38.5	3.8
1970	42.1	–1.4	37.8	4.3
1971	41.5	–2.0	37.8	3.7
1972	40.0	–3.5	36.0	4.0
1973	43.9	0.4	40.8	3.1
1974	41.6	–1.9	37.4	4.2
1975	42.1	–1.4	38.5	3.6
1976	41.2	–2.3	37.3	3.9
1977			38.6	
1978	41.1	–2.4	37.1	4.0
1979			39.5	
1980	42.0	–1.5	37.0	5.0
1981	43.7	0.2	39.4	4.3
1982	41.3	–2.2	37.6	3.7
1983			39.7	
1984	42.8	–0.2	39.0	3.8
1985	41.4	–1.6	36.9	4.5
Avg	41.87		37.9	3.98
Avg('80-85)	42.24		38.27	4.26

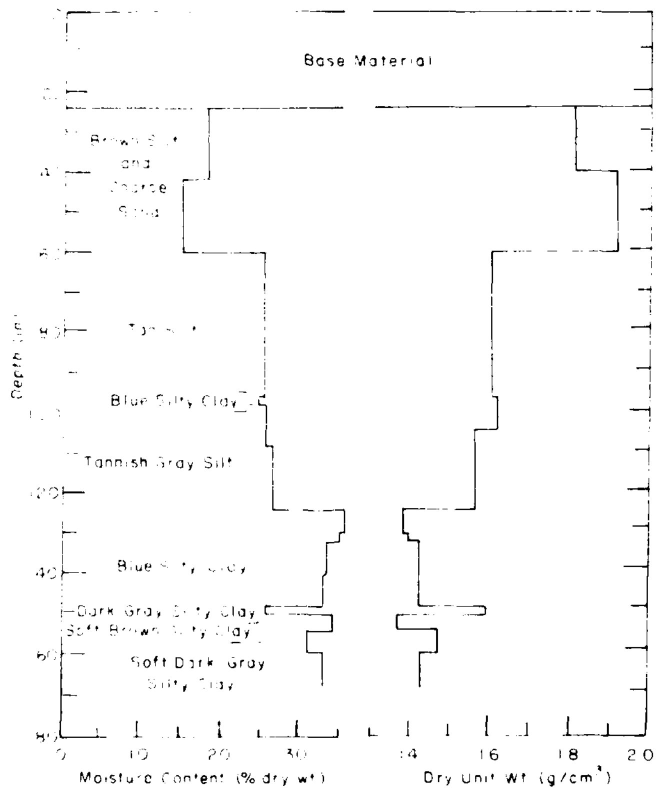
BACKGROUND

The old runway was in very poor condition, with severe differential heave and excessive cracking.

Construction specifications for the insulated pavement called for approximately 250,000 ft^2 of 2-in.-thick extruded polystyrene insulation beneath the 60- × 2900-ft runway, the 30- × 245-ft taxiway, and the 125- × 300-



a. Newton Field.



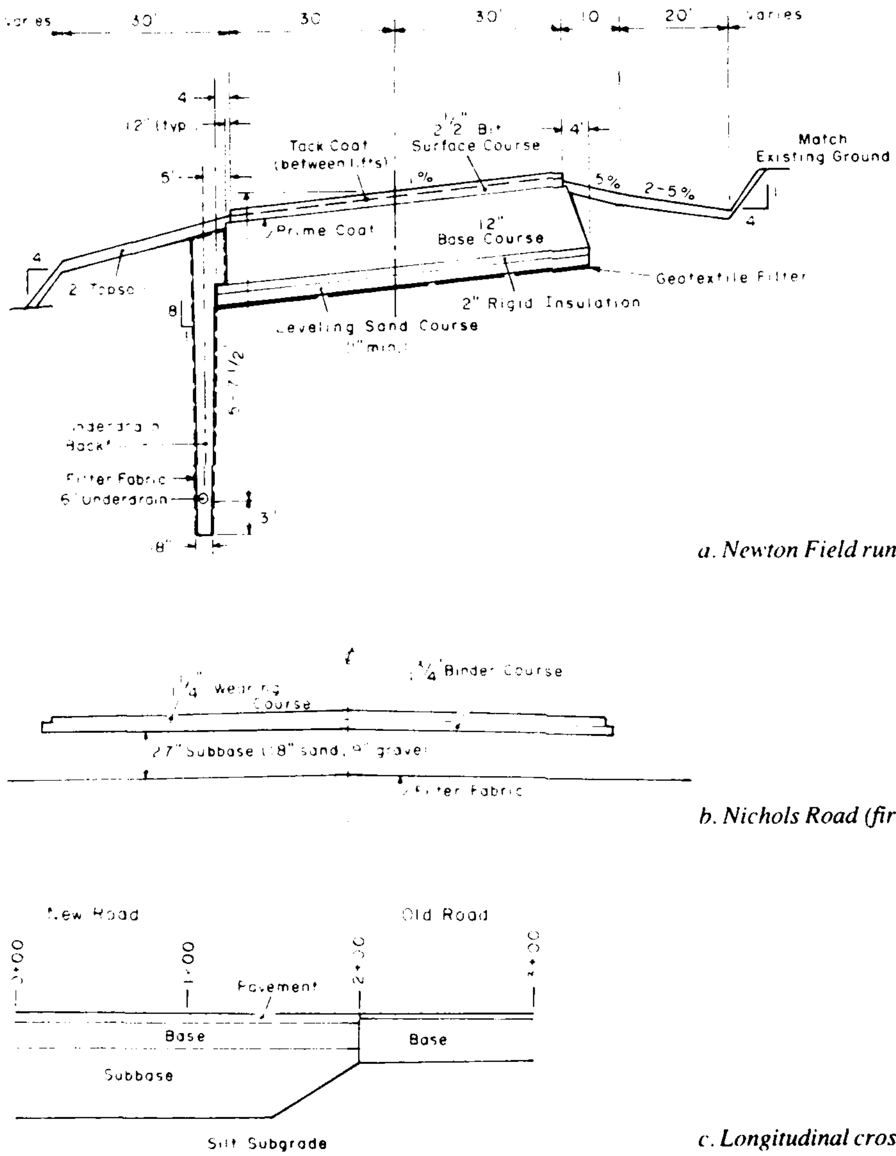
b. Nichols Road.

Figure 3. Soils profiles—Newton Field and Nichols Road.

ft parking apron, and approximately 23,000 ft^2 of 1-in.-thick extruded polystyrene insulation for the transition zone along the edges. Minimum compressive strength of all insulation was 40 psi. Ninety percent of the funding for this $1 million airport improvement construction project was provided by the FAA. The remaining 10% was shared equally by the state of Maine and town of Jackman. Drawings, specifications and contract documents were prepared by Dufresne-Henry, Inc., of Portland, Maine, and the contract was awarded to Thomas DiCenzo, Inc., of Calais, Maine.

A typical runway cross section included 2.5-in. AC pavement, a 12-in. crushed stone base, 2-in. polystyrene insulation, a 1-in. (minimum) layer of sand, and a geotextile atop the wet sandy silty subgrade (Fig. 4a).

The first few hundred feet of nearby Nichols Road were also reconstructed during the summer of 1986. The typical Nichols Road cross section shown in Figure 4b approximates the conventional, noninsulated cross section considered for Newton Field. Beyond the first 150 ft of reconstructed roadway is a 50-ft transition section into the old road (Fig. 4c).



a. Newton Field runway.

b. Nichols Road (first 150 ft).

c. Longitudinal cross section—Nichols Road.

Figure 4. Typical cross sections—Newton and Nichols Road.

Table 3. Instrumentation table.

Instrumentation/test	*Frequency of data collection*	*Purpose*	*Observations*
Thermocouples	Weekly	Subsurface temperatures	Substantial frost penetration beneath insulation.
Tensiometers	Weekly	Moisture measurement	
Air and pavement surface temperature sensors	Daily	Air and pavement surface temperatures	
Water wells	Weekly	Groundwater level	
Grid of crosses on pavement surface	Winter: monthly Spring: biweekly	Surface displacement	Substantial and differential frost heave at each end of runway.
Falling weight deflectometer and Road Rater	Spring: approx. weekly	Stiffness	Low stiffness at each end of runway.
Ground-penetrating radar		Subsurface profile	Unable to detect frost line. Varying depth to insulation.

INSTRUMENTATION

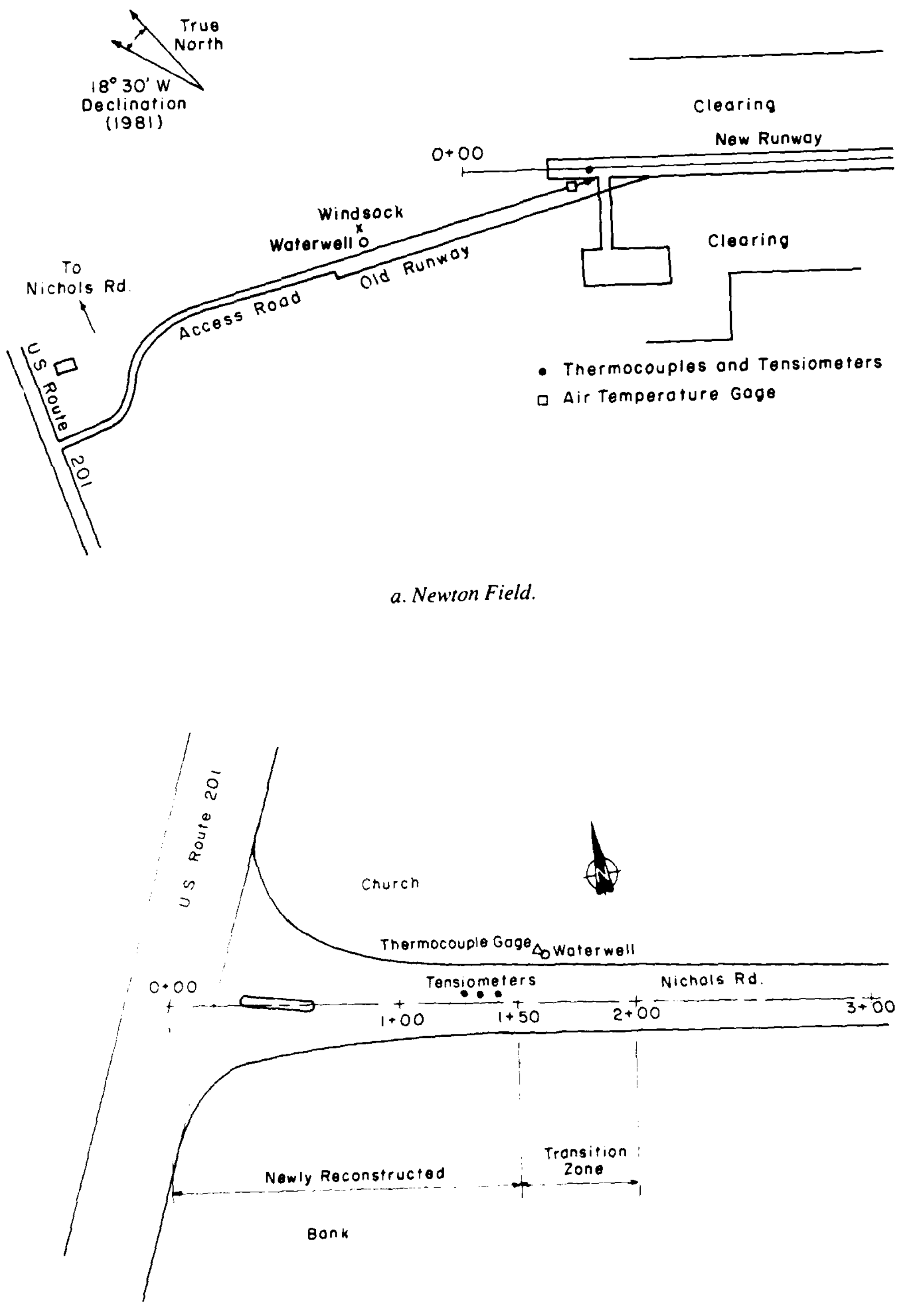
Field instruments installed at Newton Field's Runway 14/32 and Nichols Road included thermocouples to monitor subsurface temperatures and tensiometers to monitor pore water pressures in the soil. Groundwater wells were installed at each of the two observation sites. Instrumentation is summarized in Table 3. Figures 5a–6b show the instrumentation locations.

On 18 August 1986 a hole was drilled to a depth of 15 ft and soil samples were taken at Nichols Road. This hole, to be used for the thermocouple assembly, was located 1.75 ft north of the centerline at station 1+57. Drilling of a water well for determining the groundwater table at Nichols Road was completed the same day. Both the drill rig and drilling crew were provided by the Maine Department of Transportation (MDOT).

On 23 September, continuous soil samples were taken to a depth of approximately 10 ft at Newton Field. This thermocouple cable hole was located 33.5 ft from the north edge of the pavement at station 4+41.75. A 14-ft-deep groundwater well was installed approximately 50 ft from the airport's old windsock.

A large wooden box was constructed to house the airport's thermocouple and tensiometer boxes. Six horizontal holes were drilled into a single insulation panel for thermocouple installation. On Thursday, 25 September, four tensiometers were installed approximately 10 ft from the south edge of the pavement at station 4+43 at Newton Field. Thermocouples were installed at station 4+47 within the pre-drilled insulation panel, and the sensors in the backfill above the insulation were placed on 6 October 1986. Crosses were painted on the pavement surface at both Nichols Road and the runway to serve as a grid for monitoring changes in surface elevation. At the airport, these points are located on the centerline and at 5 ft and 15 ft right and left of the centerline at 25-ft intervals. The segment to be monitored spans 200 ft from station 4+00 to station 6+00. At Nichols Road, level points are near the road centerline and 5 ft left and right of the center points. Outermost points vary between 8 ft and 11 ft from center. This segment spans 300 ft from station 0+00, at the centerline of U.S. Route 201, to station 3+00.

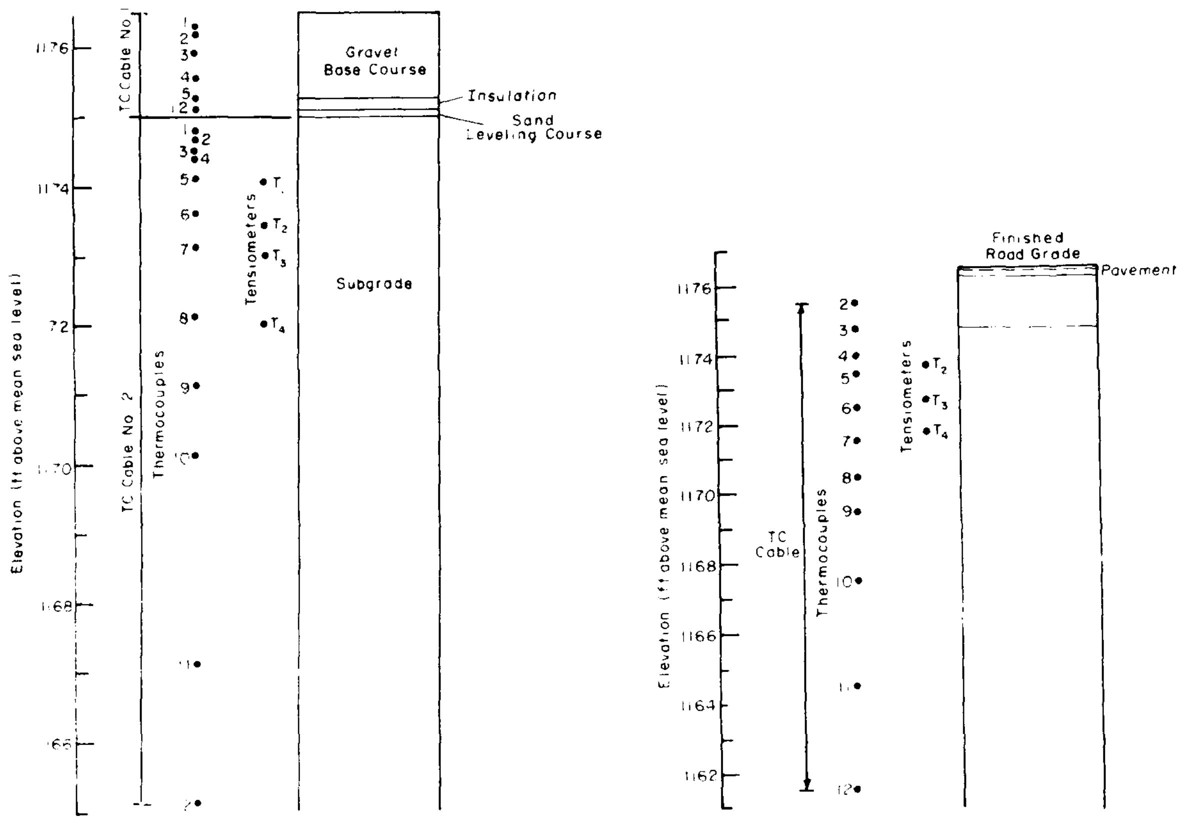
Separate markings indicate falling weight deflectometer (FWD) test points. At Newton Field, these



a. Newton Field.

b. Nichols Road

Figure 5. Proximity sketches of instrument locations.



a. Newton Field.

b. Nichols Road.

Figure 6. Profiles of instrument locations.

test points are at the following locations 5 ft from the centerline on alternating sides: 50-ft intervals from station 3+50 through station 10+00, 200-ft intervals from station 10+00 through station 30+00, and one final point at station 31+50.

Nichols Road FWD points lie along the outside wheel path at 40-ft intervals from stations 1+00 through station 3+00.

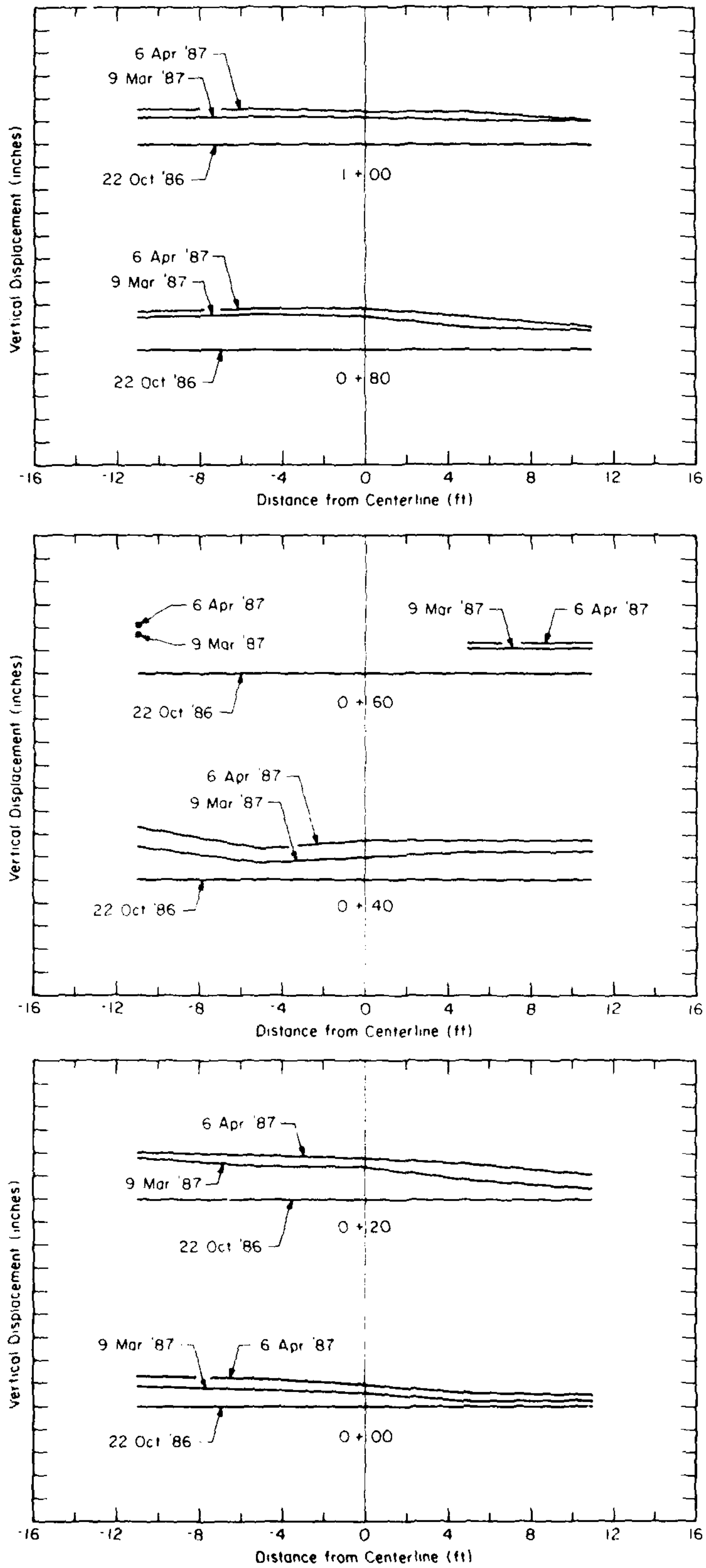
A third set of FWD points is located along U.S. Route 201 North. These 10 test points are randomly spaced along the outside wheel path from the point where new and old road surfaces meet to the Dennison town line marker. Each of the 10 points is on the old road surface.

Pavement surface elevations were taken approximately every month through the winter months and biweekly through spring thaw; thermocouple, tensiometer, and groundwater level readings were recorded weekly; air and pavement surface temperatures were monitored daily; and FWD tests were conducted approximately biweekly throughout the spring.

OBSERVATIONS AND DISCUSSION

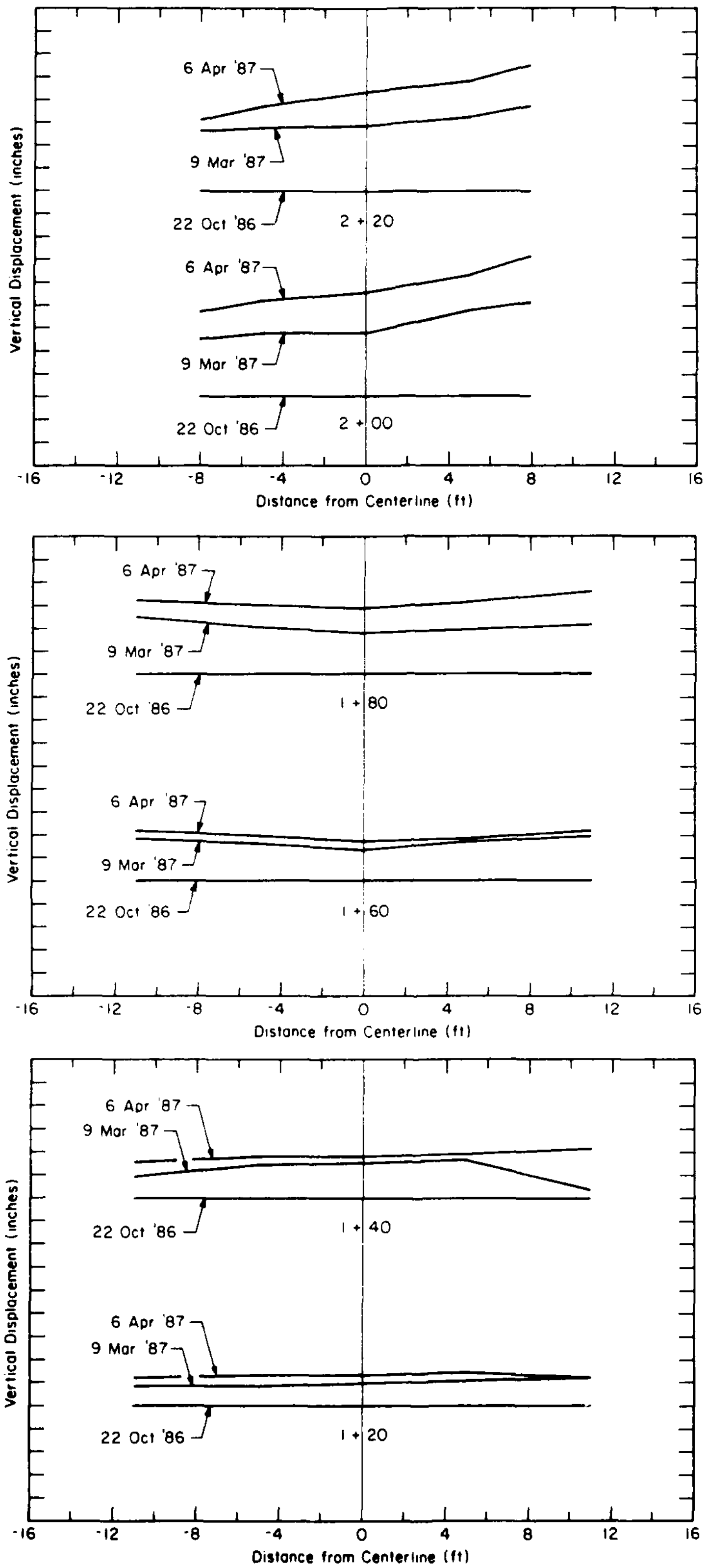
Heaving and cracking

Observed heave at Nichols Road, which served as a control site, varied from minimal to quite significant. Maximum heave was observed during March. The approximate ranges of vertical displacements exhibited by the first 150-ft, middle 50-ft, and final 100-ft segments of the observed portion of Nichols Road were 1 to 2 in., 2.5 to 3.5 in., and 3 to 6 in., respectively. For the most part, the results were as expected; the smallest average displacement occurred on the portion of Nichols Road that was reconstructed as part of the U.S. Route 201 Reconstruction Project; the largest average displacement occurred on the old road with original base/subbase; and the intermediate average displacement occurred on the transition zone (Fig. 7). Heave was relatively uniform throughout both the newly reconstructed and transition sections, but this was not the case along the old road (station 2+00–station 3+00). Vertical displacements on



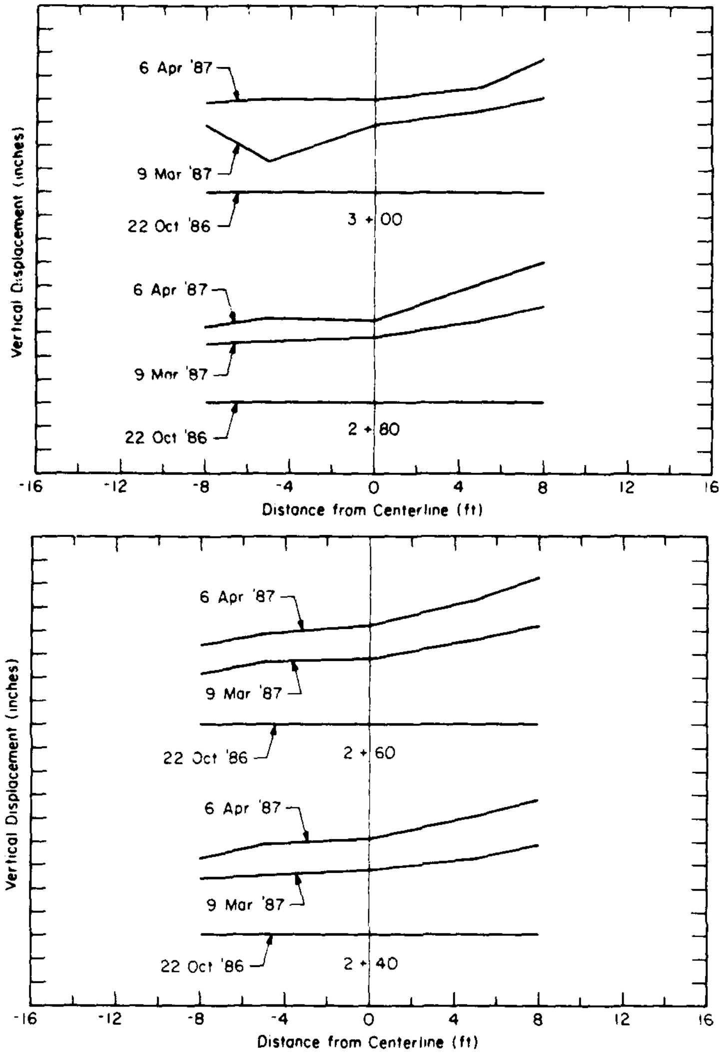
a. Stations 0+00 to 1+20.

Figure 7. Frost heave observations, Nichols Road.



b. Stations 1+20 to 2+80.

Figure 7 (cont'd). Frost heave observations, Nichols Road.



c. Stations 2+80 to 3+15.

Figure 7 (cont'd).

the left were in the range of 3 in. while those on the right approached 6 in. Generally, a fairly uniform reduction in heave was observed throughout thawing.

Results of elevation surveys of station 4+00 through station 6+00 at Newton Field showed vertical displacement values somewhat higher than expected. Maximum displacements, occurring in early March, ranged from about 2 to 4 in. with the average being 2.7 in. This exceeded the average displacement values of 1.6 and 2.6 in. corresponding to Nichols Road's newly reconstructed and transition sections, respectively (Fig. 8). Although more than expected, heave for this particular section of runway was relatively uniform throughout both the freezing and thawing seasons. Vertical displacement at Newton Field throughout the freeze-thaw process is illustrated by Figure 9. As was also the case at the opposite end of the runway, this area had been extremely wet at the time of construction.

Surface elevations were periodically taken along the centerline at 100-ft intervals down the entire length of the runway. The corresponding time vs heave profile seen in Figure 10 shows irregularities occurring in the vicinities of stations 5+00 and 17+00. The pavement profile at station 5+00 became level following spring thaw, but did not do so at station 17+00—the location of an abandoned railroad line. Since the pavement profile did not become level at station 17+00, it can be assumed that this location was either constructed to a grade higher

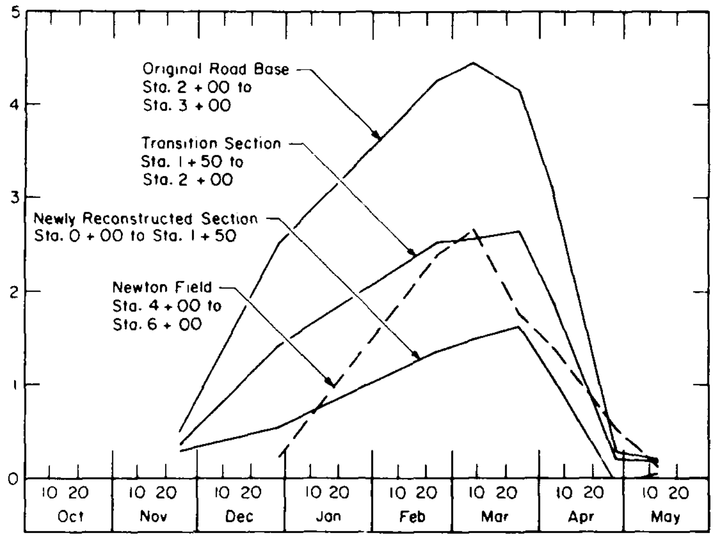


Figure 8. Average frost heave—Newton Field and Nichols Road.

than planned or the underlying railroad bed prevented station 17+00 from undergoing the consolidation experienced by surrounding areas. No initial surface elevations had been taken along centerline.

In contrast to the fairly uniform heave measured on the grid between station 4+00 and station 6+00, there were two areas that exhibited considerable differential heave. However, no initial surface elevations had been established in these areas. The first of the two areas was in the vicinity of station 8+00, where the pavement surface appeared considerably more uneven in March than in April. In addition to the uneven vertical displacement, a transverse crack developed across the entire runway at station 8+22 (Fig. 11). This particular area will be discussed in further detail with regard to ground-penetrating radar and falling weight deflectometer tests.

Even more pronounced than the differential heave near station 8+00 was the irregular pavement surface extending the last few hundred feet of the runway. This roughness was first observed in early March. In contrast to the differential heave in the vicinity of station 8+00, no improvement was apparent in April. At that time, a grid of 5-ft intervals in each direction was established from station 29+90 to station 30+10. Again, initial surface elevations are unavailable for comparative purposes, but elevations as determined on 7 April 1987 are shown in Figures 12a–c. The two most pronounced cracks in this vicinity are a transverse crack extending across the entire runway, and a discontinuous longitudinal crack approximately 50 ft in length. Six shorter cracks were also observed.

Additional cracks at locations other than the above include the following:

Taxiway—Transverse crack extending across taxiway 3 to 4 ft from and parallel to the runway/taxiway construction joint.

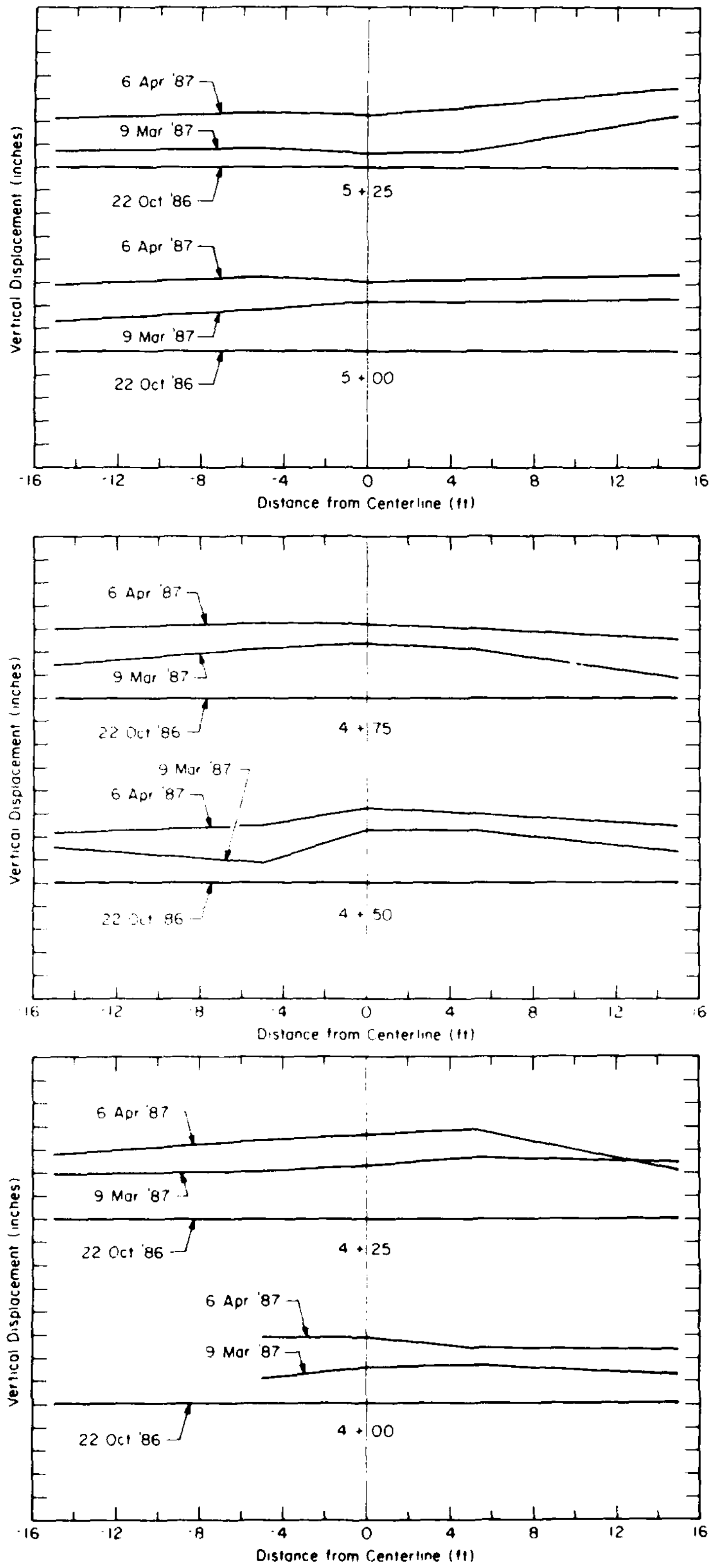
—Transverse crack extending across taxiway 60 to 70 ft from and parallel to the runway/taxiway construction joint.

Runway—Station 7+30: longitudinal crack 3 to 4 ft in length, approximately 2.5 ft left of centerline.

—Station 21+00: longitudinal crack, 2 ft in length, approximately 2 ft from left edge of pavement.

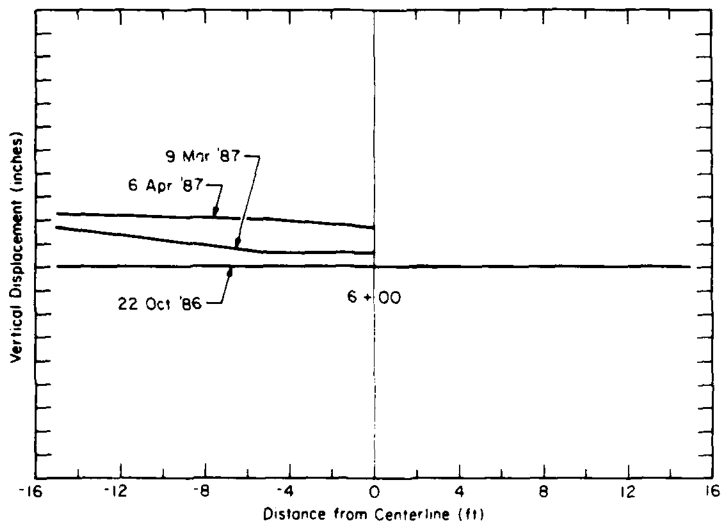
—Station 22+85 to station 23+00: two transverse cracks, left of centerline, which appear to be extensions of construction joints.

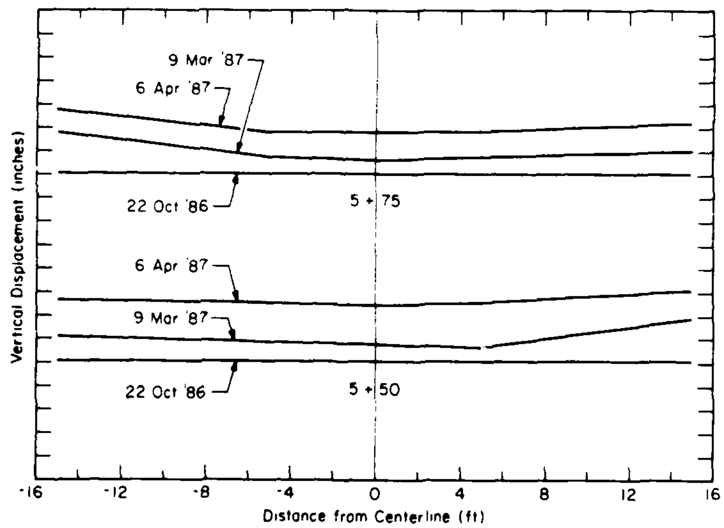
Figure 13 shows the approximate locations and orientations of the observed cracks.



a. Stations 4+00 to 5+50.

Figure 9. Frost heave—Newton Field.





b. Stations 5+50 to 6+00.

Figure 9 (cont'd). Frost heave—Newton Field.

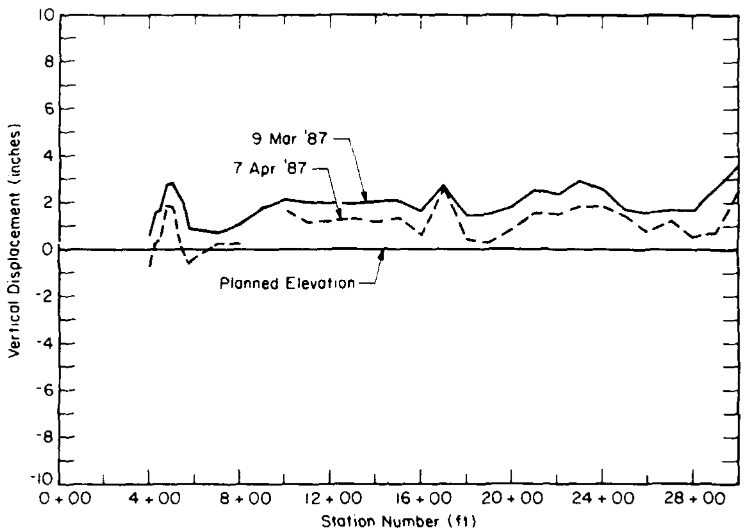


Figure 10. Surface elevations along centerline—Newton Field.

Figure 11. Crack near station 8+22—Newton Field.

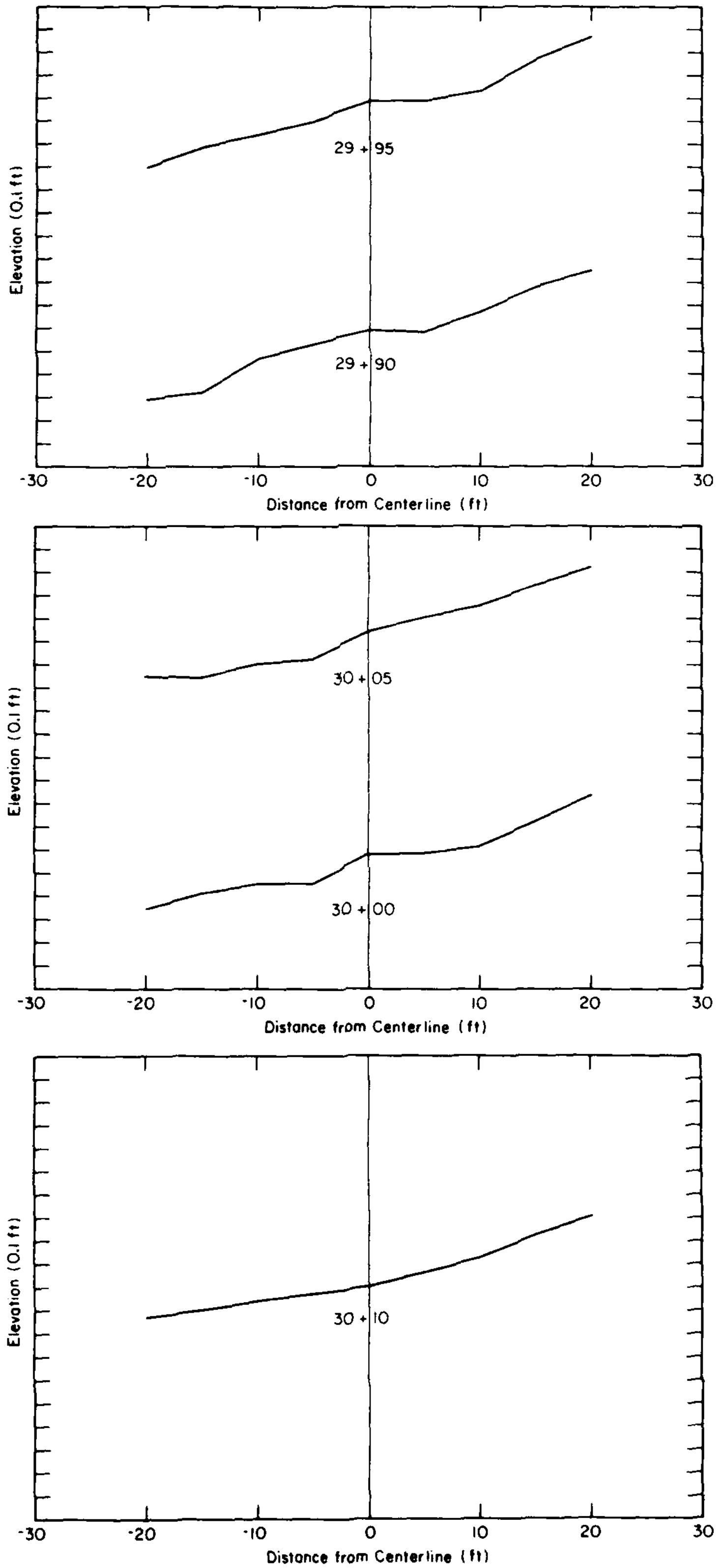


Figure 12. Cross sections depicting irregular surface near station 30+00—Newton Field.

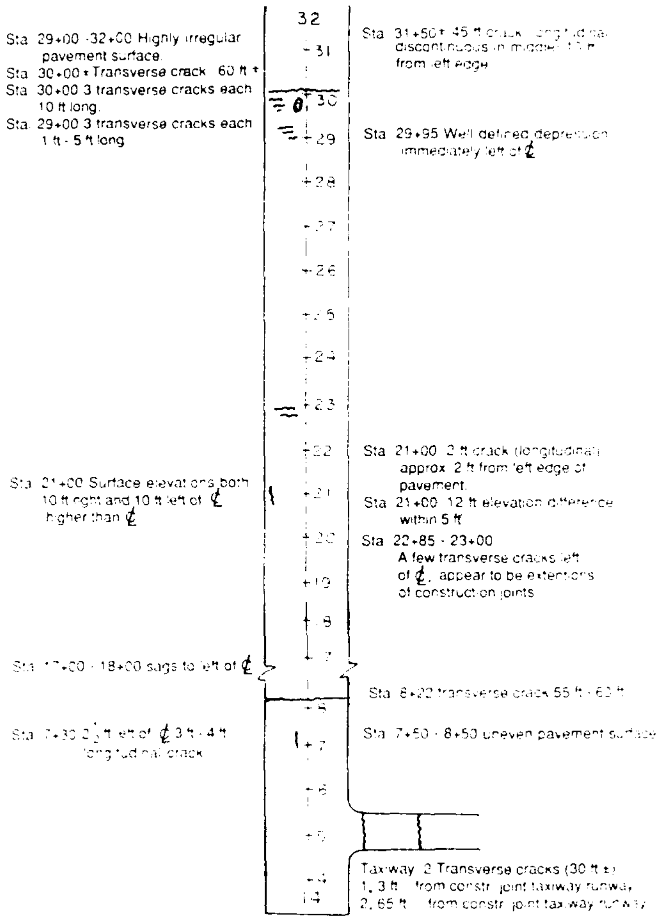


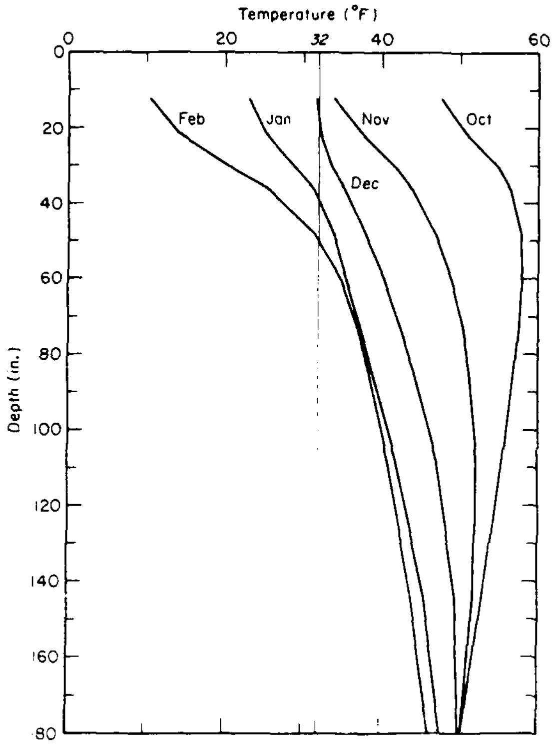
Figure 13. Approximate locations of cracks and heaves—Newton Field.

Time, temperature and depth relations

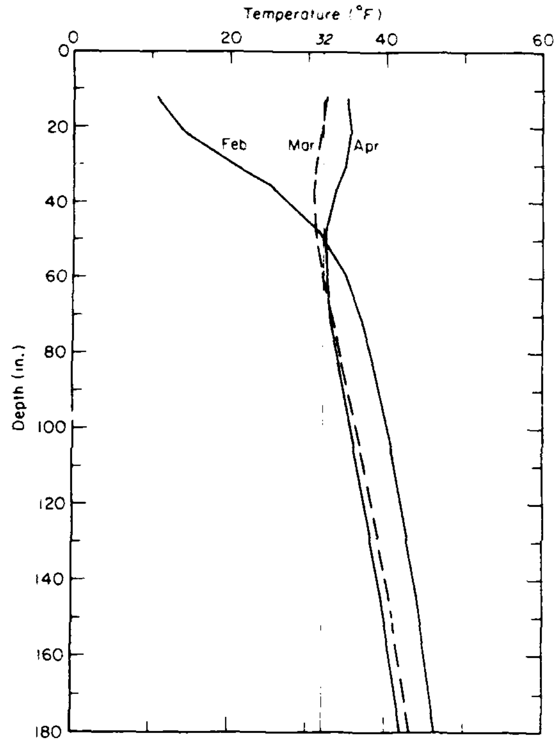
For Nichols Road, changes in temperature with increasing depth through freezing and thawing can be seen in Figures 14a and 14b, respectively. Time elapsed between selected sets of data is approximately 1 month. In both instances, the curves are typical of those expected (i.e., decreasing, followed by increasing, subsurface temperatures) through the winter and spring, respectively, and decreasing sensitivity to fluctuations of ambient air temperatures with increasing depth.

Figures 14 c–e show large temperature gradients from 16 to 18 in. reflecting the effectiveness of the insulation at Newton Field. One unexpected result was the decrease in temperature immediately below the insulation (Fig. 14e). This colder region extended to depths as great as 4 ft beneath the insulation (21 October 1986). The temperature discontinuity coincides with the transition zone between thermocouple assemblies. It starts between the deepest thermocouple of the upper assembly and the most shallow thermocouple of the lower assembly. These vertical thermocouple assemblies are separated by a few feet horizontally. The temperature fluctuation throughout spring thaw is even more erratic than that observed during the freezing season (Fig. 15). During the 1987 summer, a section of pavement at 30+00 was removed. Overlapping and damaged insulation was observed. The temperature discontinuity observed between thermocouple assemblies may be attributed to similar insulation damage in the vicinity of the instrumentation, separation of adjacent panels, or a combination of the two (Fig. 16).

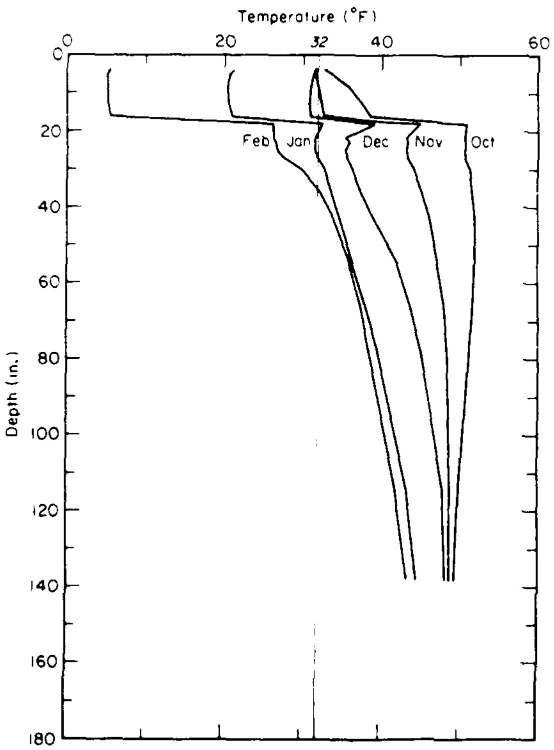
Figure 17 illustrates the dampening effect of the insulation on temperature changes with depth by comparing subsurface temperatures at both Nichols Road and Newton Field at similar depths. As is indicated by the arrows, the temperature range experienced by Nichols Road exceeded that of Newton Field at all depths below about 40 in. on the two days shown.



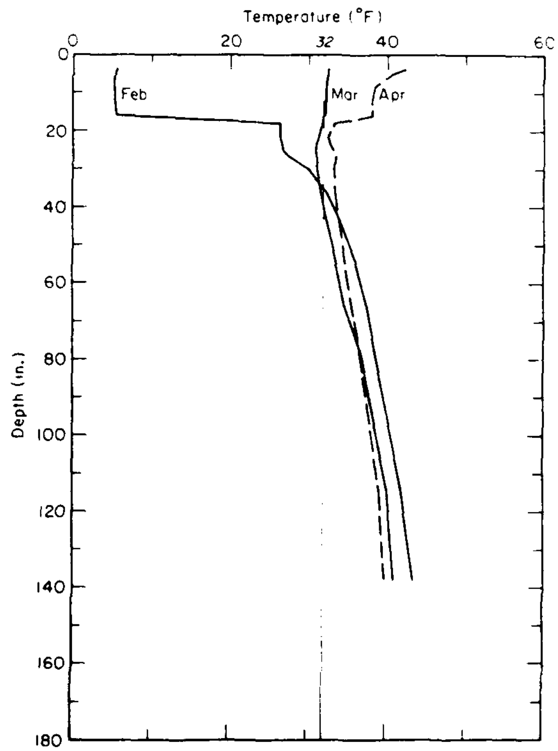
a. Temperature vs depth (freezing)—Nichols Road.



b. Temperature vs depth (thawing)—Nichols Road.

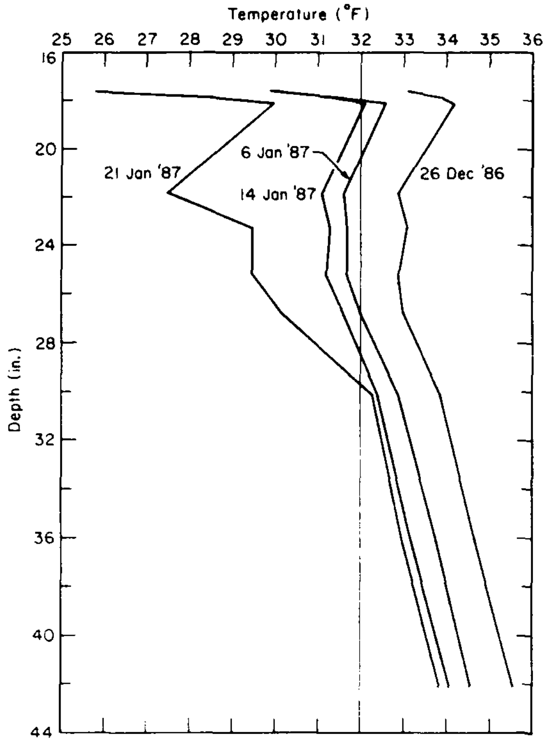


c. Temperature vs depth (freezing)—Newton Field.

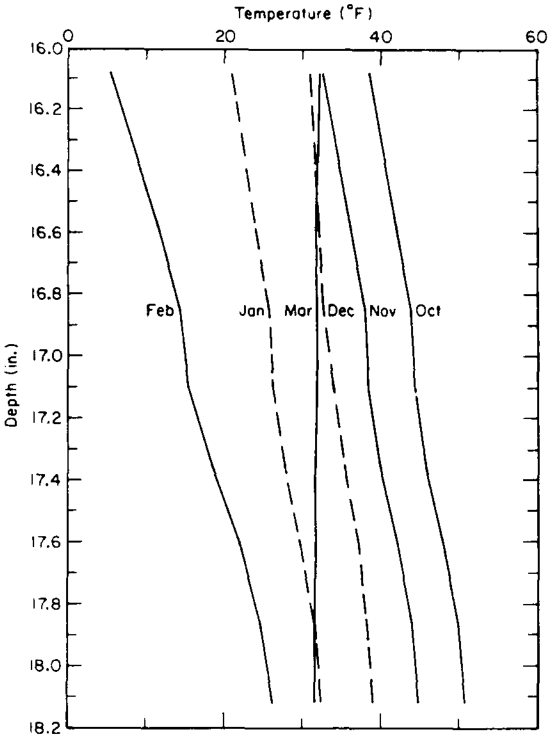


d. Temperature vs depth (thawing)—Newton Field.

Figure 14. Temperature vs depth profiles for Nichols Road and Newton Field.



e. Temperature vs depth immediately beneath the insulation (freezing)—Newton Field.



f. Temperature across the insulation (freezing)—Newton Field.

Figure 14 (cont'd).

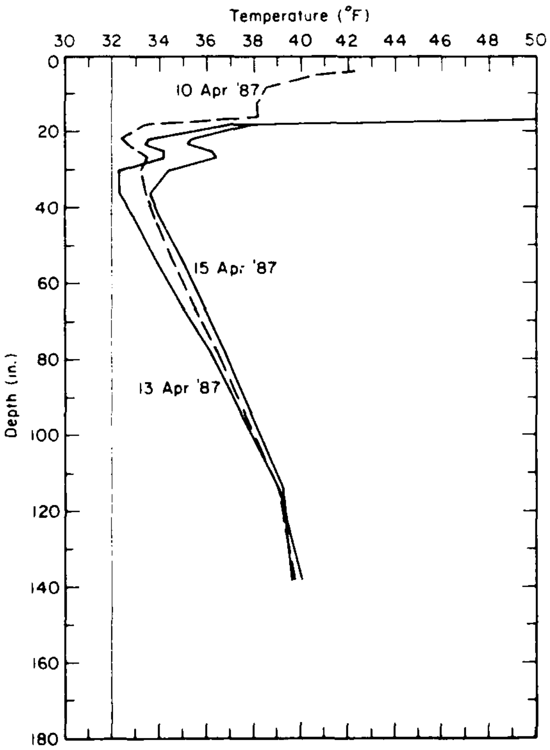


Figure 15. Temperature vs depth immediately beneath the insulation (thawing)—Newton Field.

Figure 16. Removal of pavement at station 30+00, summer 1987.

Figure 18 represents the temperature vs time relationships at the top of the insulation; within the insulation at depths of 0.5, 1 and 1.5 in.; and at the bottom of the insulation. Frost penetrated completely through the insulation in mid-January and remained beneath the insulation through early/mid-March, a period of 7 to 8 weeks.

Figure 18 illustrates temperature vs time at equivalent depths beneath the airport and Nichols Road. In the same manner that insulation reduces the cold from penetrating downward, it also serves as a shield in reducing underlying heat from being conducted upward as the freezing process begins. Assuming similar subsurface profiles, at a depth of approximately 36 in., the effect of the insulating layer is evident. From early November through early March, the average temperature at Newton Field exceeded that at Nichols Road by

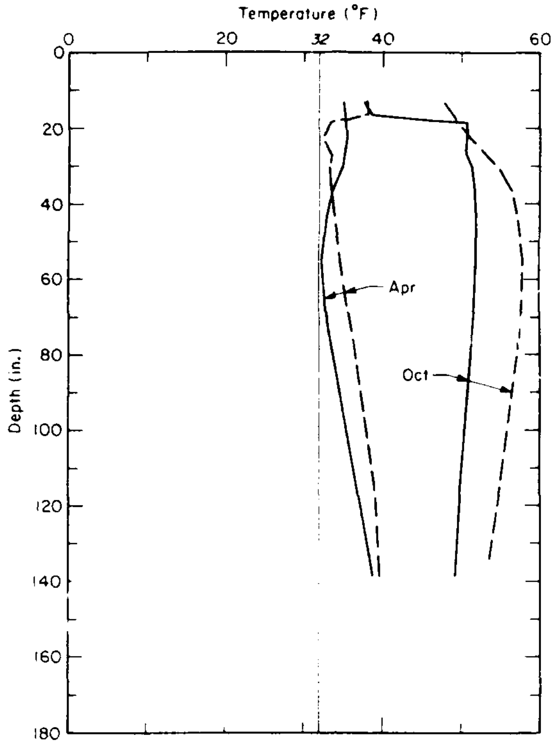
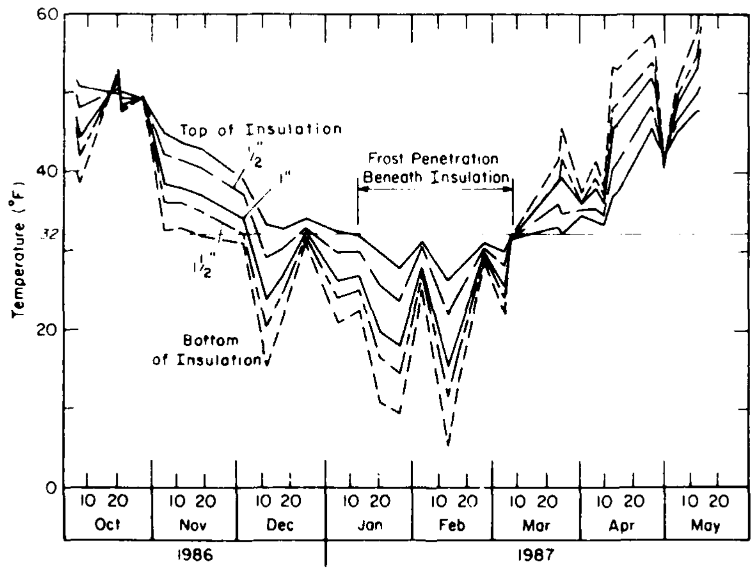
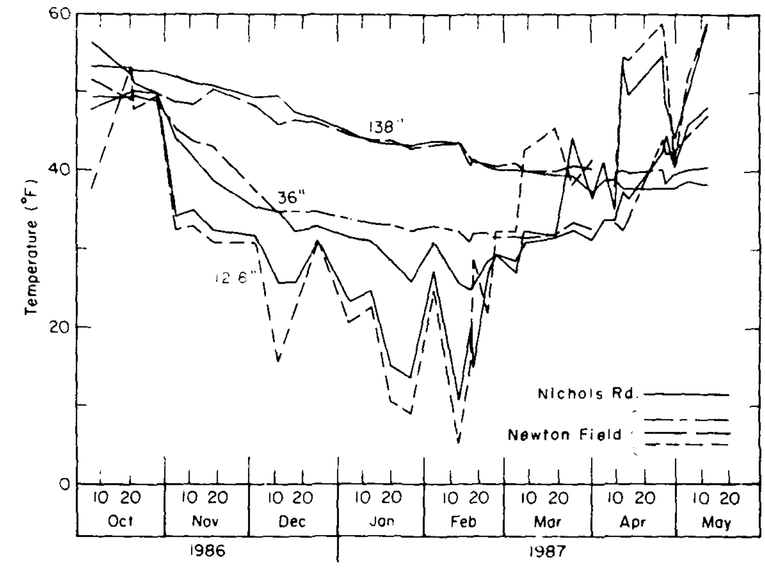


Figure 17. Temperature vs depth—Nichols Road and Newton Field.

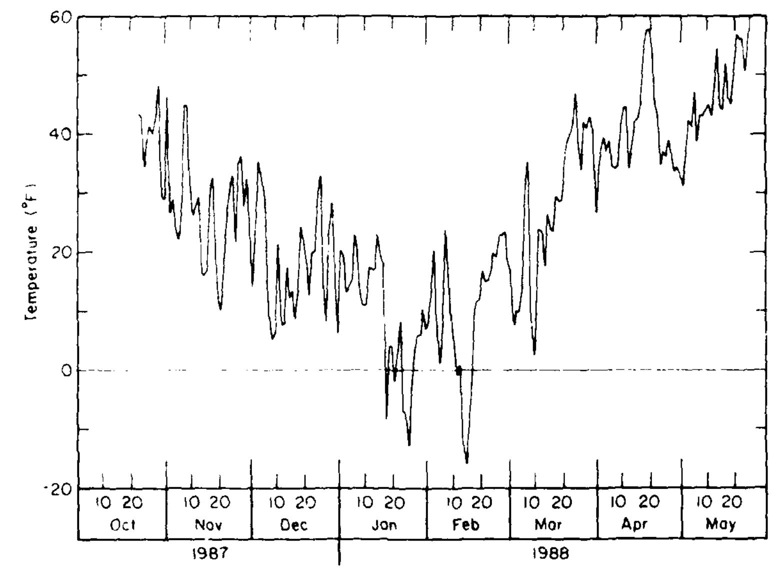


a. Temperature vs time through the insulation—Newton Field.

Figure 18. Temperature vs time plots.



b. Temperature vs time at corresponding depths—Nichols Road and Newton Field.



c. Average daily air temperature through the 1986–1987 winter.

Figure 18 (cont'd). Temperature vs time plots.

over 3°F. At the greater depth of 138 in., the effect of the insulation, although not as apparent, could still be detected.

Air temperature and freezing indices

Daily air temperatures for the 1986–1987 winter were monitored at the following locations:

1. Central Maine Power (CMP), Jackman, by CMP personnel (enclosed in CMP's standard weather bureau shelter).
2. CMP, Jackman, by CRREL personnel (enclosed in the CMP's standard weather bureau shelter).
3. Newton Field by CRREL personnel (enclosed in a vertically mounted white PVC pipe about 2 in. in diameter).
4. Nichols Road by CRREL personnel (enclosed in a vertical pipe as at the airport).

Monitoring locations 1 and 4 provided temperatures through the entire testing season, while locations 2 and 3 provided temperatures for shorter lengths of time. On a number of occasions, air temperatures at the various sites differed considerably. No trend or pattern has been determined. Temperatures obtained at the CMP meteorological shelter by CMP yielded a freezing index of –2185°F-days, whereas those obtained at Nichols Road yielded –2055°F-days. Prior to the malfunctioning of the equipment at Newton Field, the air freezing indices at Newton Field and Nichols Road were nearly identical. In order to obtain a direct comparison with CMP's temperatures, CRREL installed a temperature sensor in CMP's weather bureau shelter. Freezing indices from the two devices differed by approximately 60°F-days at the end of a 50-day period. Jackman's average daily temperature for the months of November through March was comparable to the average over the past six years. Table 4 summarizes average monthly air temperatures in Jackman since 1980, while Figure 18 depicts average daily air temperatures through the 1986–1987 winter. Newton Field's subsurface response to ambient air temperature is illustrated in Figure 19. Also shown are pavement surface temperatures measured at Nichols Road.

Table 4. Jackman's average monthly air temperatures (November–March) since 1980 (°F).

Year	*November*	*December*	*January*	*February*	*March*
1980–81	27.7	9.0	3.5	24.4	25.8
1981–82	31.3	21.3	1.3	10.8	21.8
1982–83	34.7	22.4	12.8	16.4	27.3
1983–84	32.3	13.0	7.9	22.0	16.2
1984–85	31.5	21.0	6.3	14.1	20.7
1985–86	29.3	12.2	—	—	—
1986 87	26.4	18.3	11.3	11.7	27.0
T 86–87	–4.7	+1.8	+3.8	-4.7	+4.7
T avg of yrs					

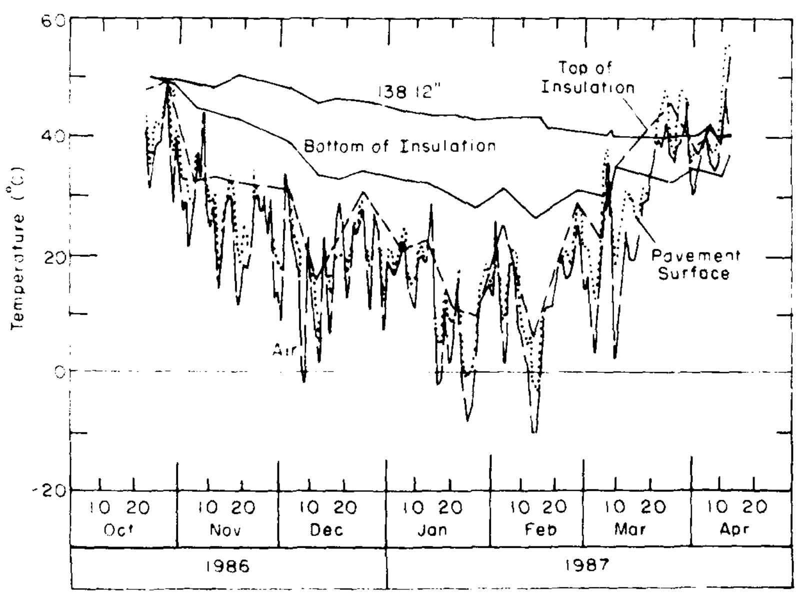
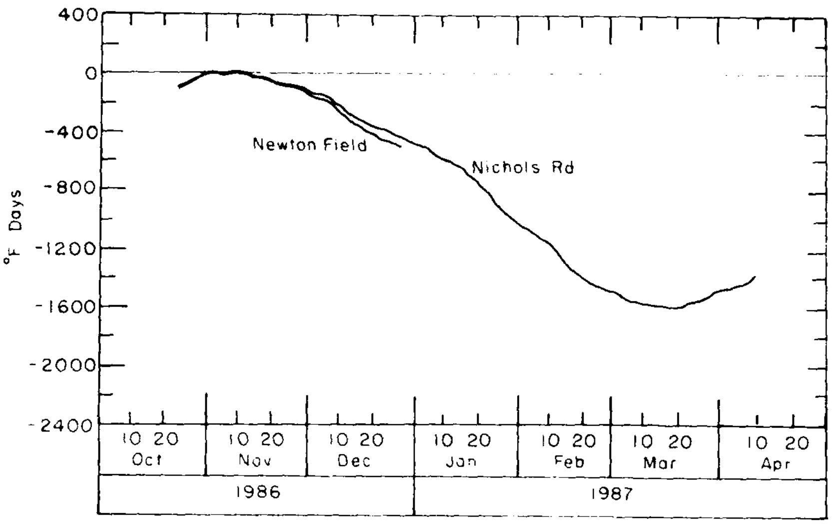
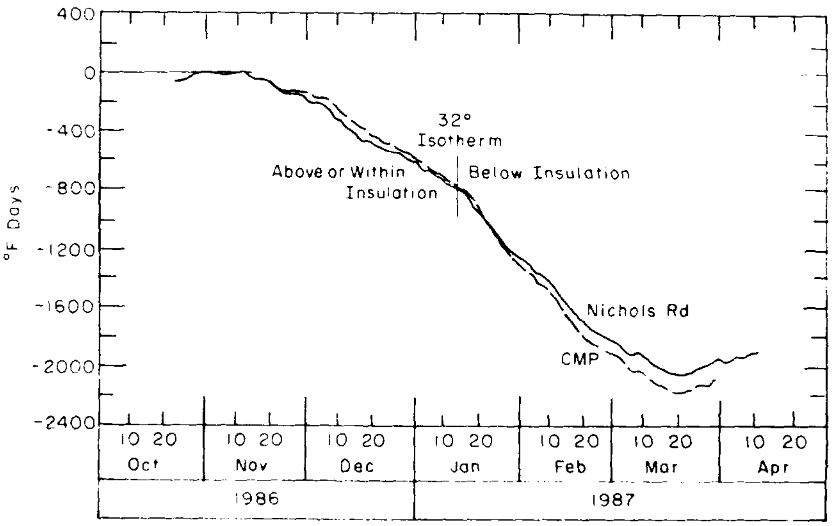


Figure 19. Air, surface, and subsurface temperature vs time.



a. Surface freezing index vs time.



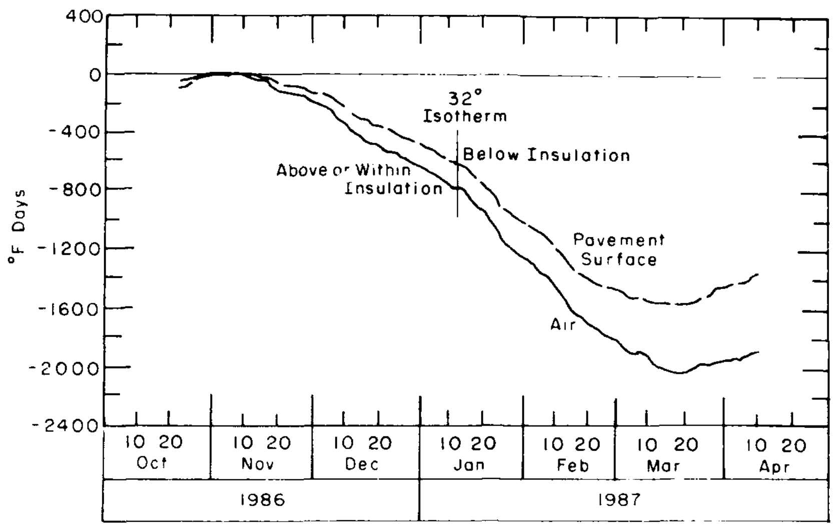
b. Air freezing index vs time.

Figure 20. Air and surface freezing indices vs time for Newton Field and Nichols Road.

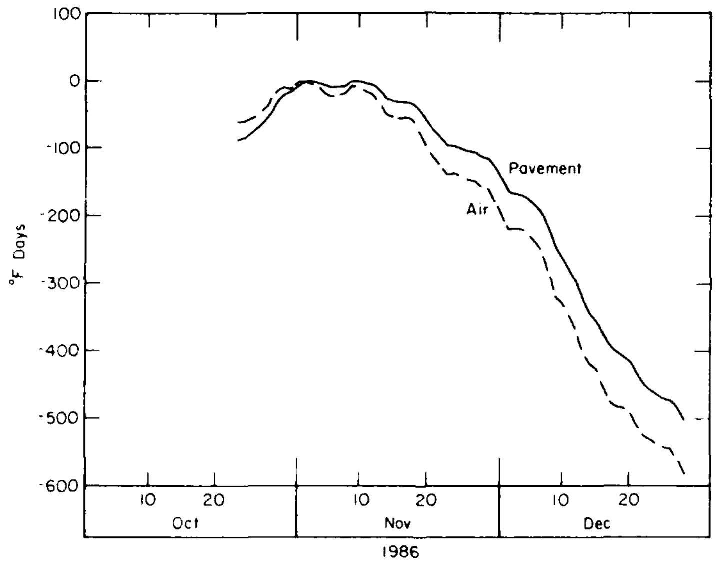
Figure 20 shows relationships among air and surface freezing indices, time, and location. Figure 20 shows surface freezing index as a function of time for both Newton Field and Nichols Road; due to malfunctioning of the Newton Field equipment, airport data are available only through 29 December 1986. The more negative surface freezing index at Newton Field is indicative of a higher n-value (ratio of surface to air freezing index) than at Nichols Road. Air freezing indices from CMP, Newton Field, and Nichols Road can be seen in Figure 20b, and comparisons between air and pavement surface freezing in Figures 20c and 20d. As discussed in the previous section, frost was determined to have penetrated completely through the 2 in. of insulation in mid-January. This frost penetration occurred only halfway through the freezing season at a freezing index of only half the total freezing index for 1986–1987 (Fig. 20d).

Frost penetration

Figure 21a shows the depth of the 32°F isotherm as a function of time at both test sites. The initial freezing of the ground at Newton Field following subfreezing tem-



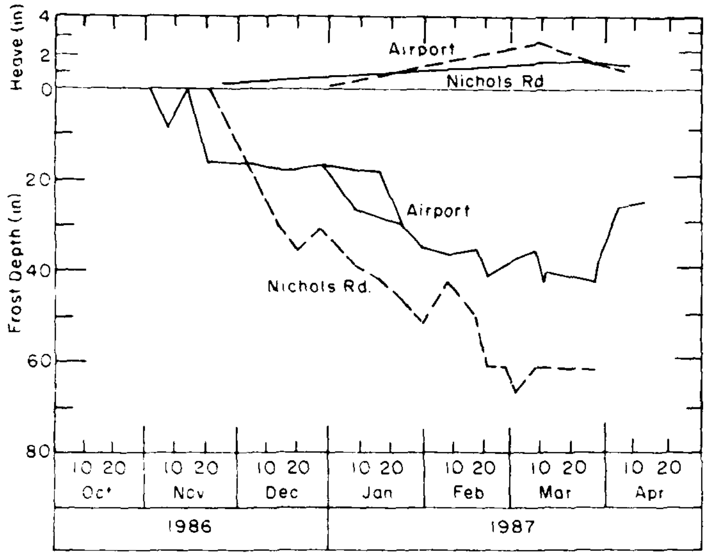
c. Air and surface freezing indices for Newton Field.



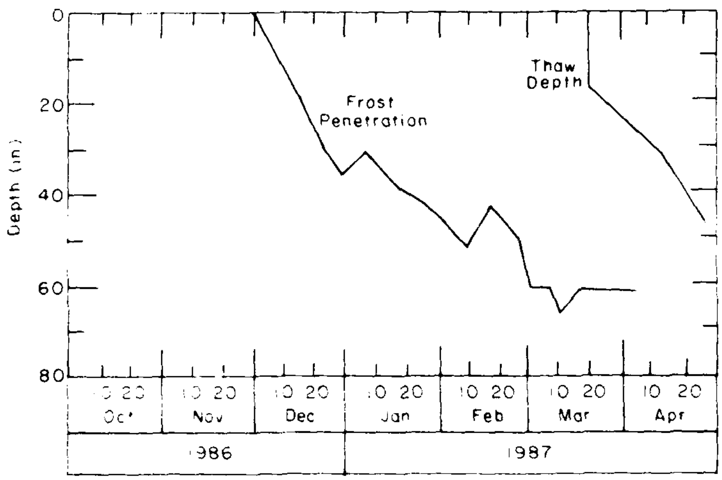
d. Air and surface freezing indices for Nichols Road.

Figure 20 (cont'd).

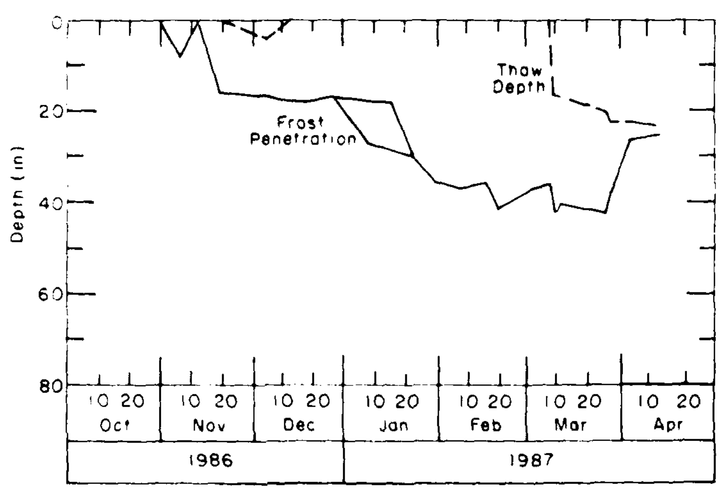
peratures during the first week of November is attributed to the insulation isolating the base course above from the heat below the insulation. Likewise, above-freezing air temperatures of 8 November and 9 November induced thawing in this same material. The pavement at Nichols Road started freezing at approximately the same time as frost reached the insulation at Newton Field. As the base course and subgrade continued to freeze to greater depths at Nichols Road, the frost line was held within the insulation at Newton Field as is illustrated by the nearly horizontal line through the middle of January. The temperature discontinuity probably caused by gaps and/or damaged insulation discussed earlier resulted in two different frost depths (thus the double frost line) throughout the greater part of January. The dashed line represents computed frost penetration depths, if the insulation is assumed to be intact. This approximation of frost penetration is based upon the modified Berggren equation (Aitken and Berg 1968) (Table 5). Based upon thermocouple readings, maximum frost penetration was approximately 66 in. at Nichols Road and 42 in. at Newton Field. With the exception of Newton Field's



a. Frost depth vs time—Nichols Road and Newton Field.



b. Frost/thaw depth vs time—Nichols Road.



c. Frost/thaw depth vs time—Newton Field.

Figure 21. Depth vs time for Nichols Road and Newton Field.

Table 5. Frost penetration depths computed using the modified Berggen equation. Newton Field—maximum frost depth = 42 in. (thermocouple Readings) Air freezing index = 2185°F-days, length of freezing season = 139 days (CMP) Surface freezing index = 1439°F-days (n = 0.85).

Dry density (PCF)	Water content of base course (weight %)	Thermal conductivity of insulation (BTU/°F hr ft)	Thickness of insulation (in.)	Frost penetration (in.)
130	6	0.0145	2	24.5
130	6	*0.015	2	24.7
130	6	**0.01775	1.2	29.8
130	6	0.0145	1	29.3
130	6	—	0	55.1
130	10	0.0145	2	24.8
130	9	0.0145	2	24.8
130	8	0.0145	2	24.7
130	7	0.0145	2	24.8
130	6	0.0145	2	24.5
130	5	0.0145	2	24.5
130	4	0.0145	2	24.2
130	3	0.0145	2	24.0
130	2	0.0145	2	23.8
130	1	0.0145	2	23.2
135	8	0.0145	2	24.8
135	6	0.0145	2	24.6
135	1	0.0145	2	23.3
120	13	0.0145	2	25.0
120	8	0.0145	2	24.6
120	1	0.0145	2	23.0
135	8		—	57.2
135	1		—	46
120	13		—	56.2
120	1		—	40.5

* Thermal conductivity supplied in UC Industries Literature (UC Industries 1986).

**Thermal conductivity for insulation compressed to 1.2 in.

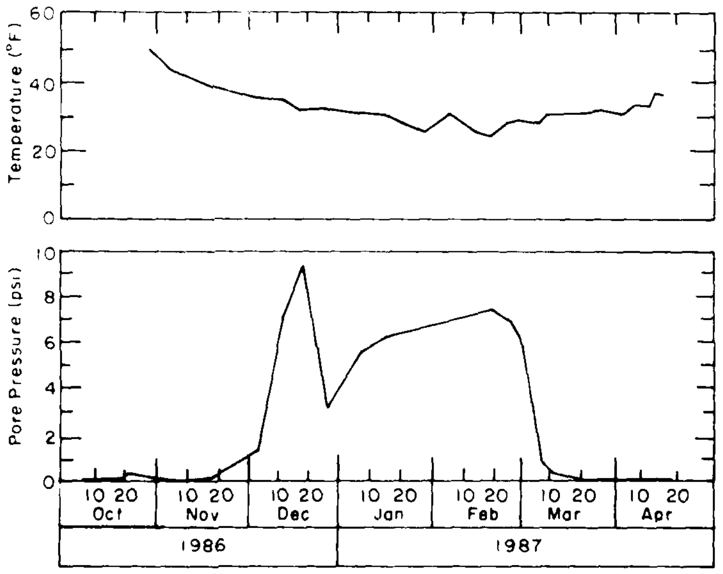
double frost depth line (6–28 January 1987), the rate of frost penetration at Newton Field is less than at Nichols Road, illustrating the effect of the insulating layer. Figure 21 illustrates thawing as it occurred from the surface downward, as well as from the lower frost line upward. Two thermocouple recorders were used during spring thaw. Since one detected some subfreezing temperatures while the other indicated total thaw, depths of frost and thaw through the end of March or beginning of April have been approximated by the dashed lines.

Depths at which the tensiometers indicated increased pore pressures coincided with those at which the thermocouples recorded subfreezing temperatures (Fig. 22). Pore water tensions beneath Nichols Road increased rapidly as the frost line penetrated, indicating a movement of moisture to the freezing front and lowering of the water table. Pore water pressures beneath Newton Field increased rapidly when the frost line penetrated beneath the insulation (Fig. 21c) because of the large tensions imposed by the subgrade soil as it was frozen.

Ground-penetrating radar

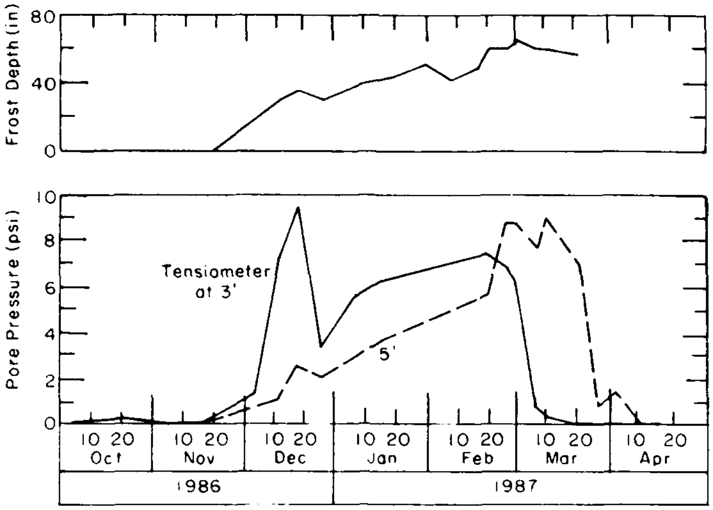
To understand the reason for the decrease in temperatures beneath the insulation (i.e., the insulation might be damaged or the panels separated) and to obtain a profile of the frost line, ground-penetrating radar tests were conducted on 25 and 26 March 1987 at both Nichols Road and Newton Field. The insulation was discernible on the radar record, but the frost line could not be detected.

Typically a change in water content occurs at the interface between any two subsurface layers. This change, and thus the interface, can be detected by

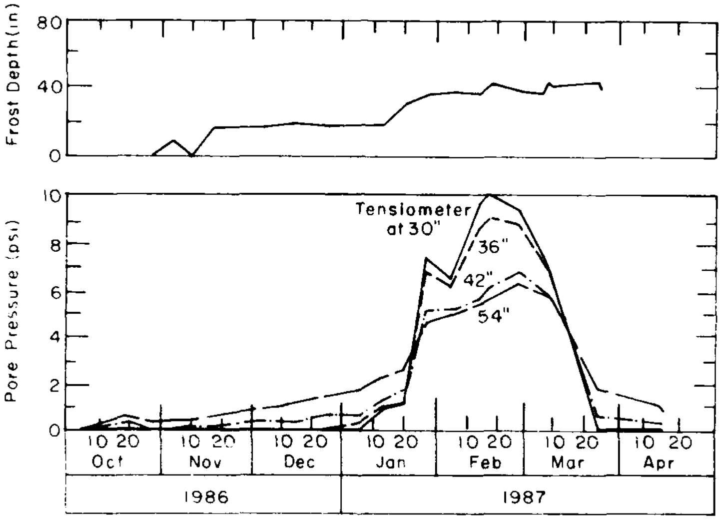


a. Nichols Road—tensiometer readings at 3-ft depth.

Figure 22. Correlations between tensiometer readings and frost determined by thermocouple readings.



b. Nichols Road—tensiometer readings at 3- and 5-ft depths.



c. Newton Field—tensiometer readings at 30, 36, 42, and 54 in.

Figure 22 (cont'd). Correlations between tensiometer readings and frost determined by thermocouple readings.

ground-penetrating radar. Return time of radar emissions can be correlated to depths based upon known or estimated dielectric constants of the materials and ground truth (known depths to particular features). The resulting printout, referred to as the radar "record," takes on the appearance of the subsurface profile. Since no cores for ground truth could be taken, holes were dug on the north side of the runway 2 to 3 ft beyond the edge of the pavement at stations 7+00, 8+00, and 9+00 to the insulation (Fig. 23). The ground-penetrating radar device was pulled transversely across the runway at these stations, and the resulting record yielded a time depth of 5.4 nanoseconds /ft (which corresponds to a dielectric constant of 7.2). Table 6 shows the approximate depths to the insulation at stations 7+00, 8+00, and 9+00.

If we assume the gravel between the insulation and pavement to be of uniform water content, approximate depths from the pavement surface to insulation have been calculated at centerline and 10 ft right of centerline (Fig. 24). Plans specify 12 in. of base course above the insulation, and a final thickness of bituminous surface course of 2.5 in., of which 1.5 in. was in place at the time of the radar tests. This implies approximately 13.5 in. from pavement surface to insulation. Table 7 shows

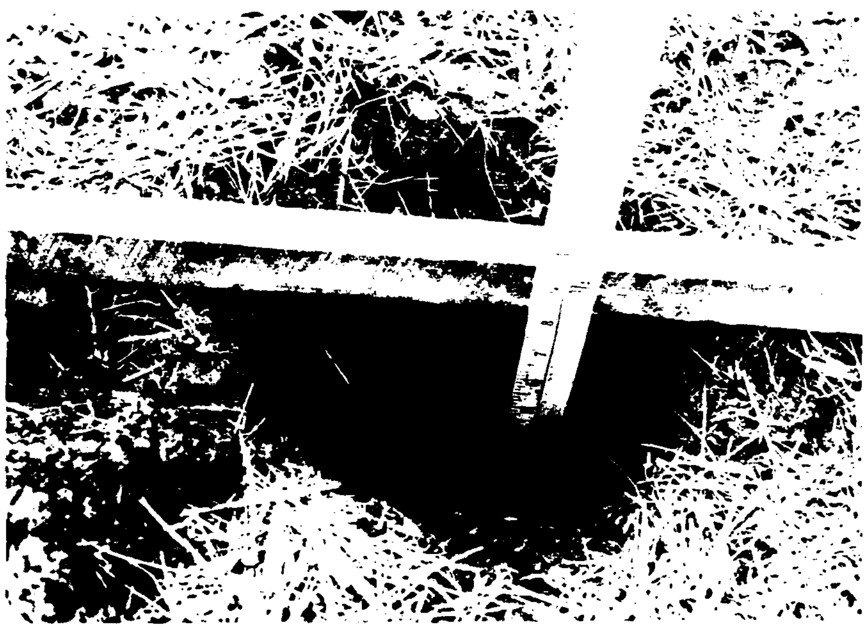


Figure 23. Known depth to insulation used for ground-penetrating radar calibration.

Table 6. Times and depths to insulation at cross sections at stations 7+00, 8+00, and 9+00 determined by ground-penetrating radar tests. (Time is in nanoseconds and depth is in inches.)

Location (points along cross section)	*Station 7+00*		*Station 8+00*		*Station 9+00*	
	Time (ns)	*Depth (in.)*	*Time (ns)*	*Depth (in.)*	*Time (ns)*	*Depth (in.)*
Adjacent to north edge of A/C pavement	8	18	2.5	6	3.5	8
North edge of A/C pavement	7.5	17	2.5	6	3.5	8
Centerline	6.5	14	3	7	6	3.5
Approximately 8 ft from south edge of A/C pavement	—	—	8.5	19	—	—
South edge of A/C pavement	5.5	12	5.5	12	5.5	12

Table 7. Depths from ground surface to top of insulation measured alongside the edge of runway.

Station	*Left (in.)*	*Right (in.)*
4 + 50		15
7 + 00	16	
7 + 50	9	
8 + 00	7	
8 + 17	6	10.5
8 + 22	7	11
8 + 27	7.5	12.5
8 + 50	7.5	12.5
9 + 00	7	13.5
9 + 50	12	
10 + 00	9	10.5
15 + 00	13	10.5
20 + 00	13.5	14
25 + 00	13	15.5
27 + 00		12
30 + 00	9	

actual depths to insulation at either side of the runway, and Table 8 shows calibrated depths to insulation at the centerline and 10 ft right of the centerline. The two tables show the insulation to be within 6 in. of the pavement surface in the vicinity of station 8+00 to station 9+00. A radar record parallel to and offset 5 ft from the transverse crack at station 8+22 also shows the proximity of the insulation (2nd set of dark bands) to the surface (Fig. 25a). The lower insulation surface 5 to 15 ft right of the centerline in Figure 25a coincides with a repair patch which is visible on the pavement surface. This same region is seen longitudinally in Figures 25b and 25c, the former representing a centerline run, the latter, parallel to and 10 ft right of the centerline. In these figures, the

insulation also appears too close to the surface. The third set of dark bands in each radar record was determined to be a secondary reflection of the insulation and not the frost line.

The subsurface profile around station 30+00, the other area which had experienced differential heaving and cracking, does not reveal any insulation abnormalities (Fig. 25d). Ground-penetrating radar tests were also conducted in the vicinity of the thermocouple cables (Fig. 25e). No insulation abnormalities large enough to be detected by the radar were observed. As discussed earlier, overlapping and damaged insulation was observed following the removal of a section of pavement at station 30+00 during the 1987 summer. These gaps in the insulating layer were not detected by the radar. It was not expected that the radar would detect gaps of such small magnitude beneath the pavement and base course.

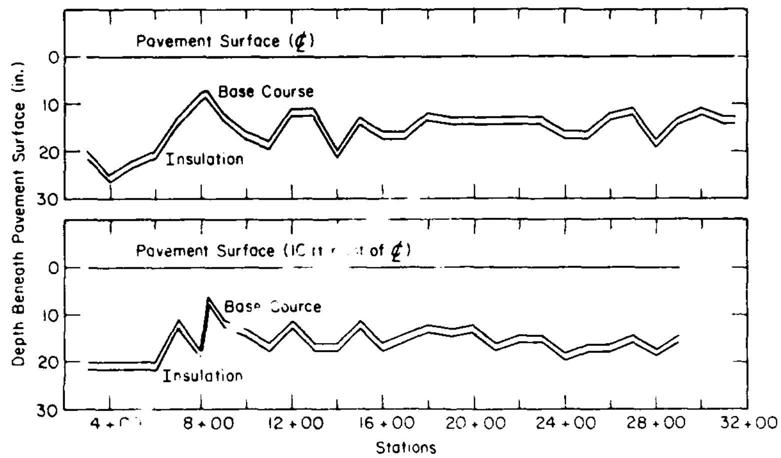
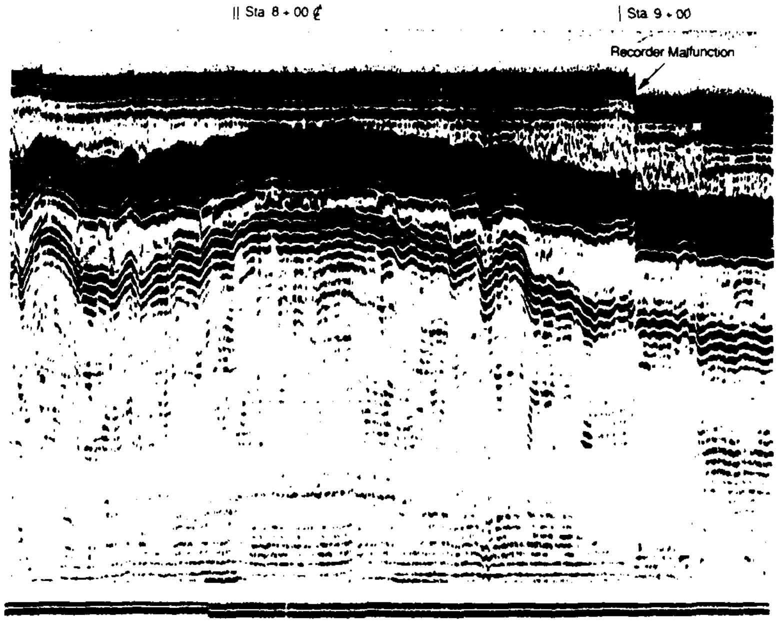


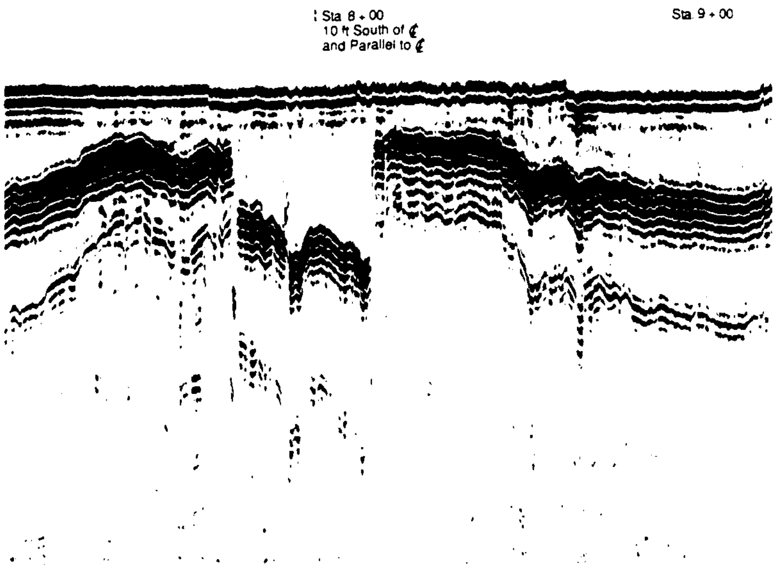
Figure 24. Ground-penetrating radar profile of insulation.

a. Radar record parallel to transerve crack at station 8+22.

Figure 25. Ground-penetrating radar record, Newton Field.

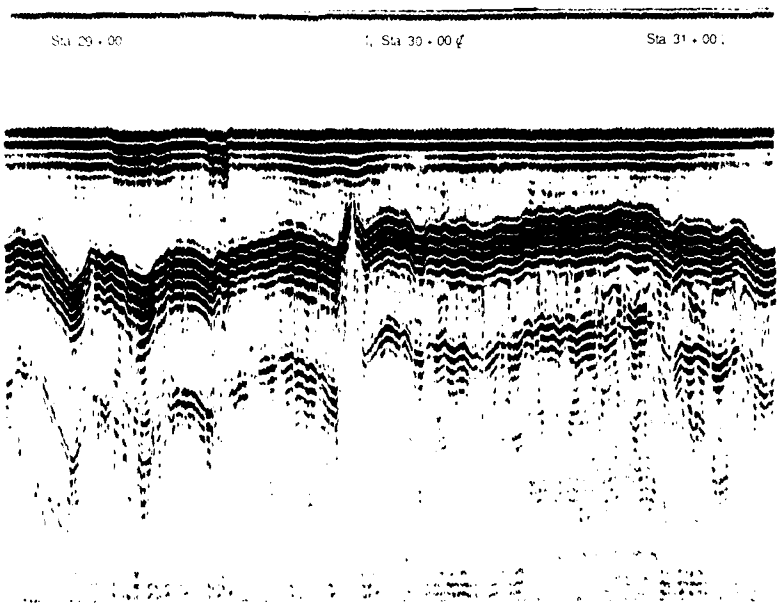


b. Longitudinal radar record along centerline, station 8+00 to station 9+00.

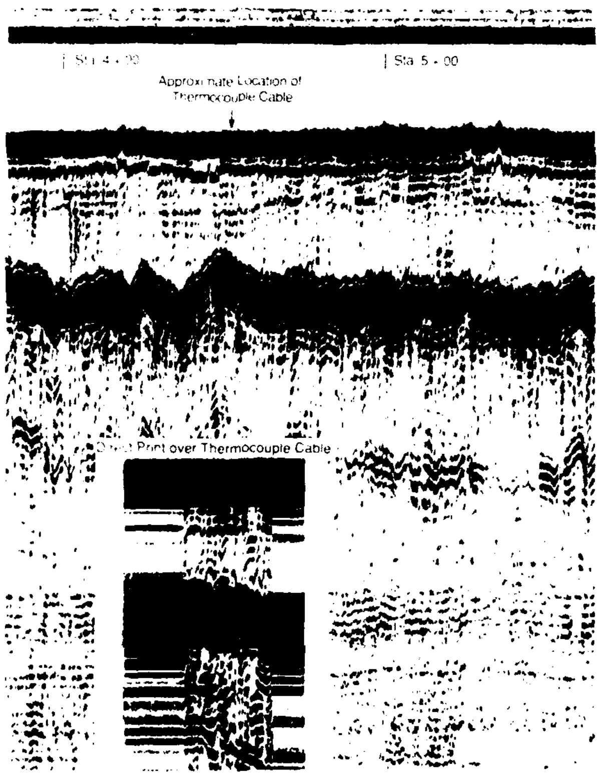


c. Longitudinal radar record 10 ft right of and parallel to centerline, station 8+00 to station 9+00.

Figure 25 (cont'd).



d. Longitudinal radar record along centerline, station 29+00 to station 31+00.



e. Radar record across thermocouple cables near station 4+50.

Figure 25 (cont'd). Ground-penetrating radar record, Newton Field.

Table 8. Approximate depths to insulation determined by ground-penetrating radar.

	Depth to insulation (in.)	
Station	*Centerline*	*10 ft right of centerline*
3 + 00	20	20
4 + 00	25	20
5 + 00	22	20
6 + 00	20	20
7 + 00	12	11
8 + 00	8	18
8 + 30	7	6
9 + 00	12	11
10 + 00	16	13
11 + 00	18	16
12 + 00	11	11
13 + 00	11	16
14 + 00	20	16
15 + 00	13	11
16 + 00	16	16
17 + 00	16	—
18 + 00	12	12
19 + 00	13	13
20 + 00	13	12
21 + 00	13	16
22 + 00	13	14
23 + 00	13	14
24 + 00	16	18
25 + 00	16	16
26 + 00	12	16
27 + 00	11	14
28 + 00	18	17
29 + 00	13	14
30 + 00	11	—
31 + 00	13	—
31 + 50	13	—

Falling weight deflectometer

Falling weight deflectometer tests were conducted periodically from 20 March through 14 May 1987. A sixth set of FWD tests was conducted on 15 October 1987 following the placement of the final 1-in. lift of pavement during the 1987 summer. FWD tests at or near Newton Field's station 4+50, station 8+00, and station 30+00 yielded lower stiffness values than did those along the rest of the runway (Fig. 26a). Similarly, all runway values are markedly lower than those at Nichols Road and at random locations along U.S. Route 201 north of Jackman (Fig. 26b). FWD tests conducted through 14 May 1987 show no appreciable increase in stiffness. A lower water table and, in the case of the runway, an increase in pavement thickness probably contributed toward the increase in stiffness moduli of 15 October 1987. On two occasions, pavement strength tests were conducted at the FWD test sites with MDOT's Road Rater. The Road Rater is a nondestructive pavement stiffness testing device that utilizes a steady-state vibratory load. Although test results from the two devices were fairly similar (Fig. 24c), on 7 April 1987 deflections measured by the Road Rater at stations 8+00 and 30+00 exceeded the deflection limits of the equipment.

SUMMARY AND CONCLUSIONS

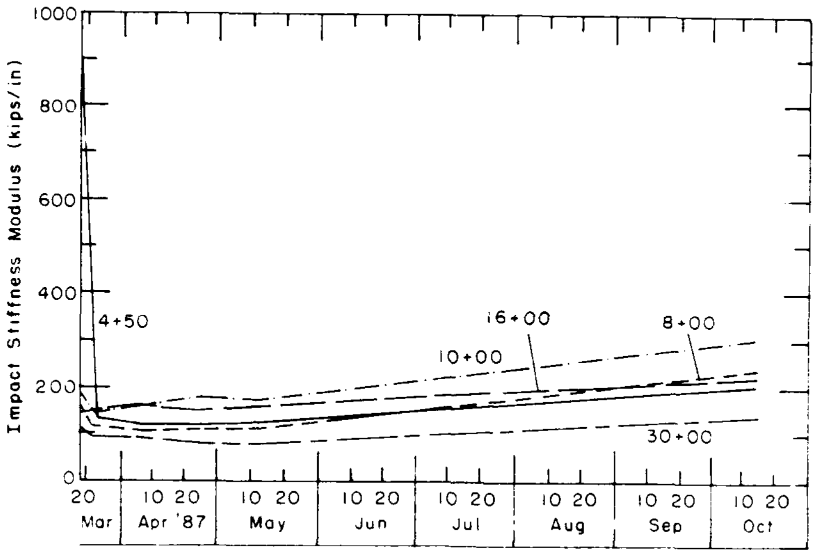
1. Frost penetrated beneath the insulation at Newton Field; it reached the bottom of the insulation by mid-January when the freezing index was only half its design value and only half the freezing season had gone by (Table 9).

2. The entire runway did experience frost heaving: In most instances the heave was uniform; however, both station 8+00 (and vicinity) and station 29+00 to station 32+00 exhibited differential frost heaving (during March and April 1987) as well as cracking.

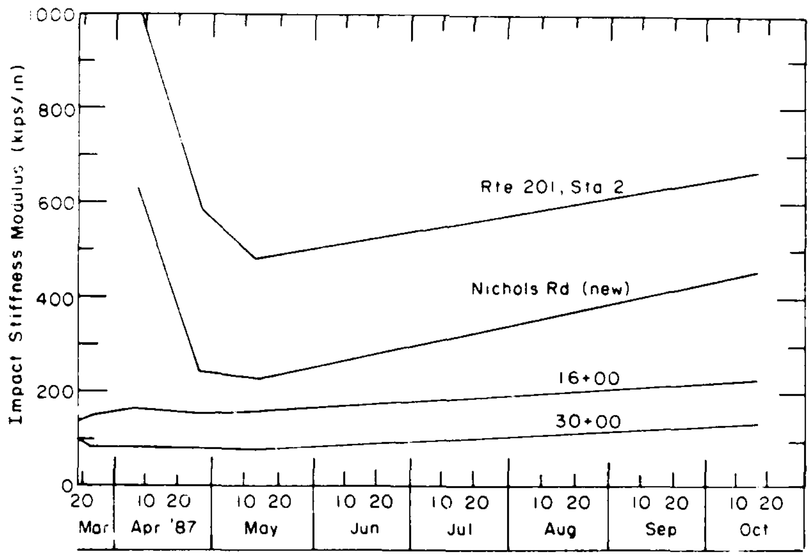
3. If the base course above the insulation is assumed to be of uniform water content, ground-penetrating radar showed the insulation near station 8+00 to be considerably closer to the surface than beneath the remainder of the runway.

4. Relationships among temperature, depth, and time were typical of those expected with the exception of the noticeable decrease in temperature immediately beneath the insulation at Newton Field. Throughout freezing, lower temperatures were recorded in this sub-insulation region to depths as great as 4 ft beneath the insulation. The temperature discontinuity occurs at the break between the two thermocouple assemblies. Proposed explanations include damaged insulation, separation between adjacent insulation panels, or a combination of the two.

5. Both falling weight deflectometer and Road Rater tests showed the stiffness values of station 8+00 and station 30+00 to be somewhat lower than those of the remaining airport test sites. Likewise, the average stiffness values at the airport proved to be significantly lower than those of Nichols Road and U.S. Route 201 North of Jackman.

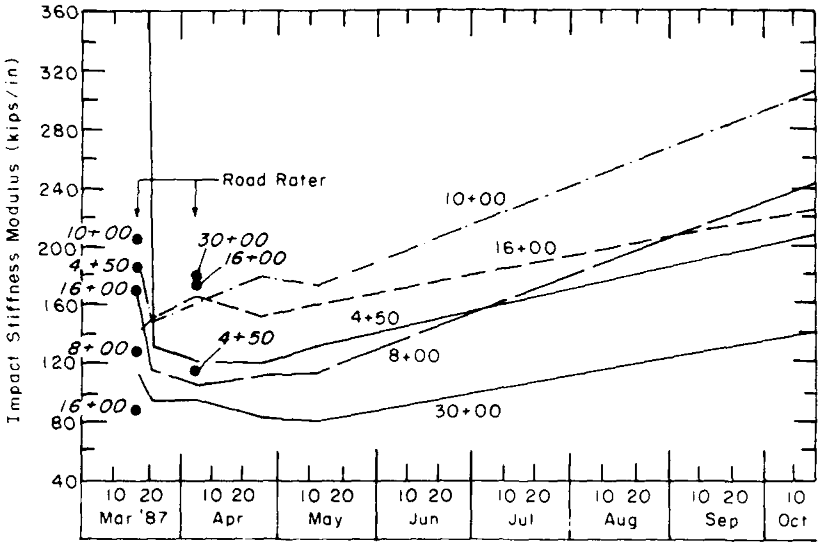


a. FWD—Newton Field.



b. FWD—Newton Field, Nichols Road, and U.S. Route 201.

Figure 26. Impulse stiffness modulus vs time.



c. Road Rater results—Newton Field.

Figure 26 (cont'd).

Table 9. Summary of observations.

Observations	*Newton Field*		*Nichols Road*		
Maximum frost depth	42 in.				66 in.
			New	*Transition*	*Old*
Maximum average heave	2.7 in.		0.6 in.	2.6 in.	4.5 in.
	8+00	*30+00*			
Nonuniform heave, cracks	X	X			
Insulation is probably closer to surface than specified in plans.	X	—			
Low pavement stiffness	X	X			

LITERATURE CITED

Aitken, G.W. and R.L. Berg (1968) Program for the modified Berggren equation. USA Cold Regions Research and Engineering Laboratory, Special Report 122.

Davis, J. and R. Johnson (1987) Overlays, insulation protect airfields' pavement bases. *Airport Services Management*, March, p. 41–44.

Fournier, P. (1986) Remote Jackman Airport tries insulated runway. *New England Construction*, December 8, p. 15–17.

Prue, F.J. and M.W. Morgan (1970) Soils investigation for Moose River Project F-033-2(1), Maine Department of Transportation Internal Report.

UC Industries (1986) Extruded polystyrene insulation foamular. Parsipanny, New Jersey.

APPENDIX A: GRADIATION, HYDRAULIC CONDUCTIVITY, AND MOISTURE RETENTION DATA.

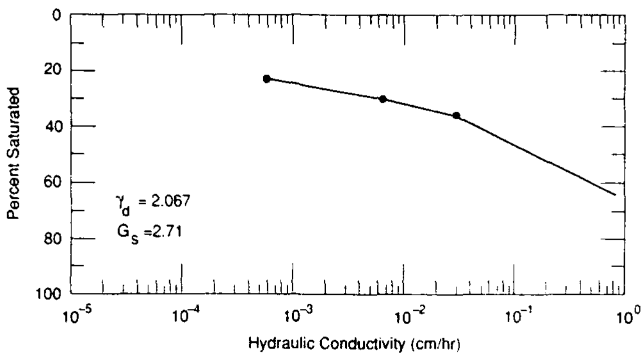


Figure A1. Hydraulic conductivity—Newton Field, gravel base.

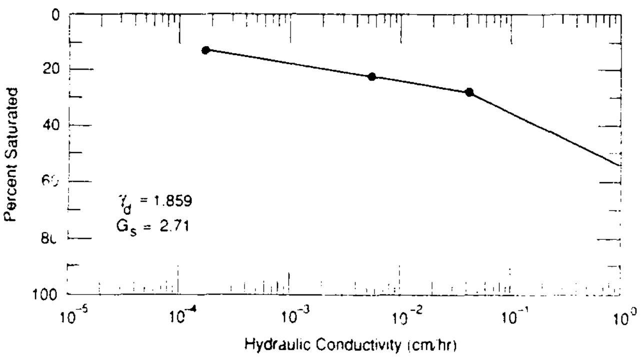


Figure A2. Hydraulic conductivity—Newton Field, sand subbase.

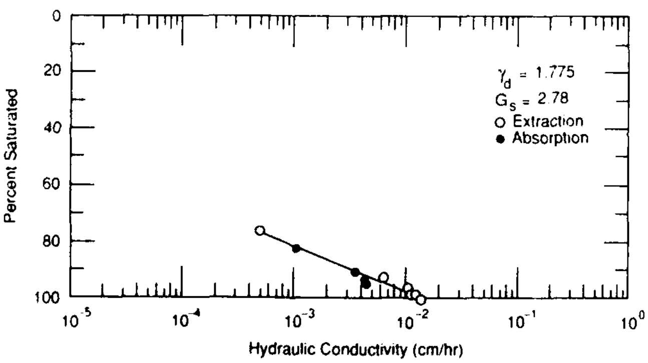


Figure A3. Hydraulic conductivity—Newton Field station 4+55, subgrade.

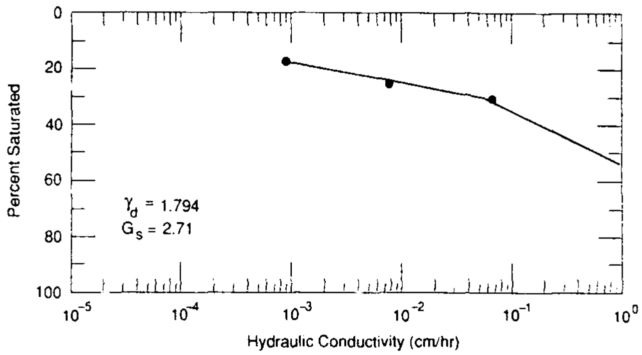


Figure A4. Hydraulic conductivity—Nichols Road, sand subbase.

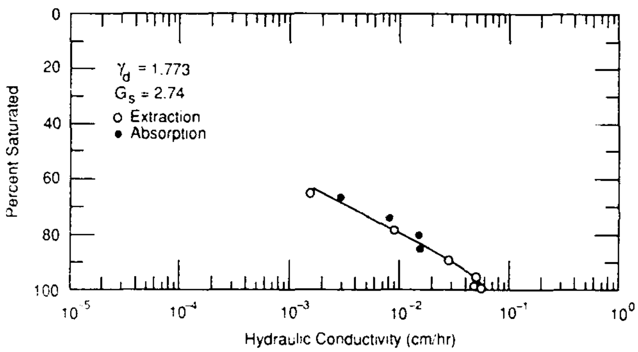


Figure A5. Hydraulic conductivity—Nichols Road, subgrade 3 ft deep.

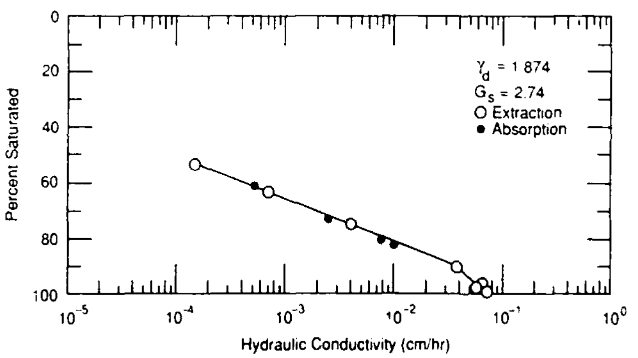


Figure A6. Hydraulic conductivity—Nichols Road, subgrade 4 ft deep.

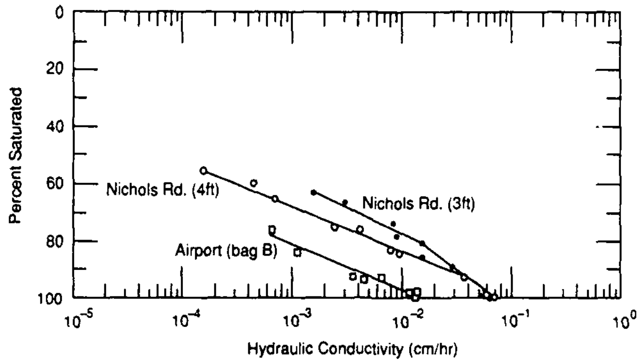


Figure A7. Hydraulic conductivity—subgrade soils.

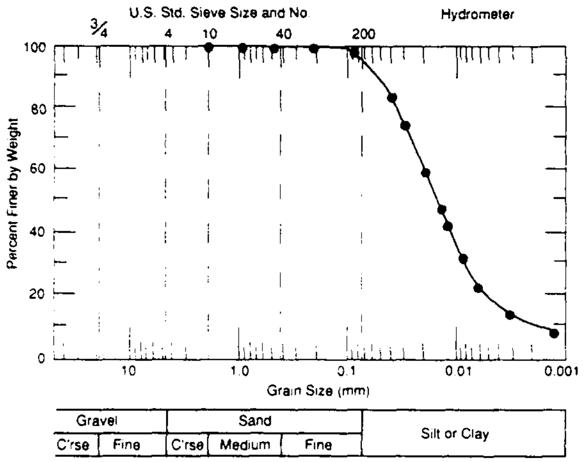


Figure A8. Grain size distribution—Newton Field, subgrade 1.5- to 3-ft depth, nonplastic.

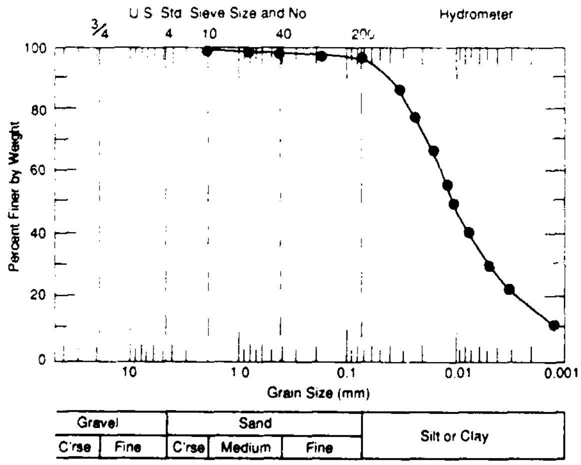


Figure A9. Grain size distribution—Newton Field, subgrade 4.5- to 6-ft depth, liquid limit = 23, plastic limit = 22, plasticity index = 1.

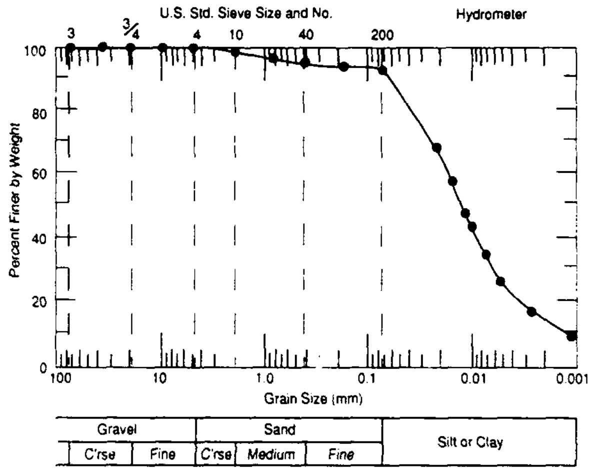


Figure A10. Grain size distribution—Newton Field, subgrade, liquid limit = 22, plastic limit = 21, plasticity index = 1.

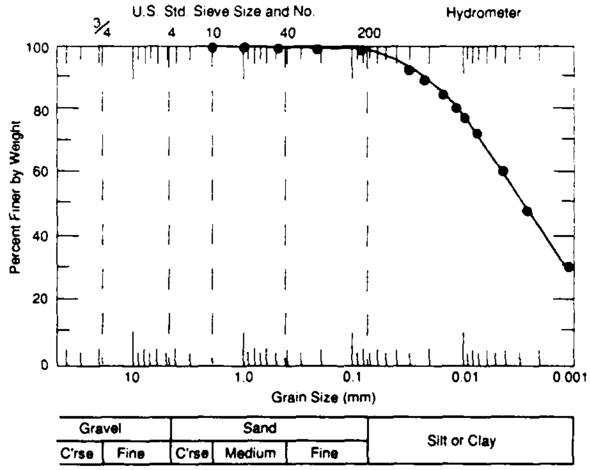


Figure A11. Grain size distribution—Newton Field, subgrade 10-ft depth, liquid limit = 29, plastic limit = 19, plasticity index = 10.

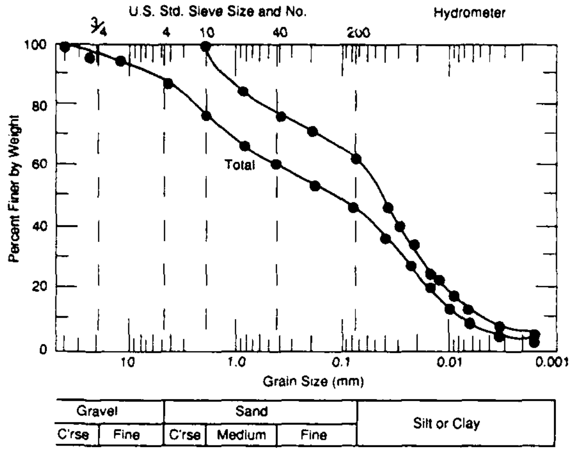


Figure A12. Grain size distribution—Newton Field, subgrade, nonplastic.

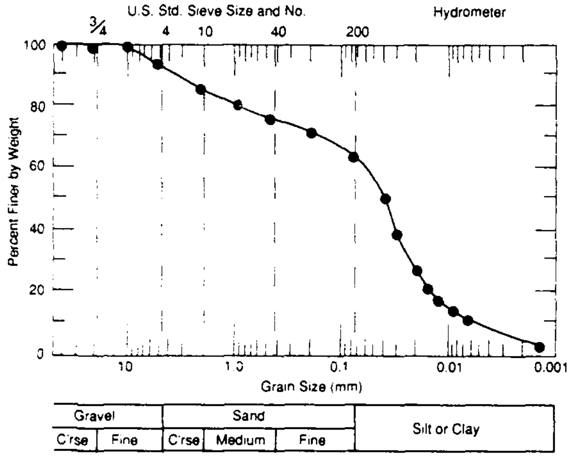


Figure A13. Grain size distribution—Nichols Road, subgrade at 3-ft depth, nonplastic.

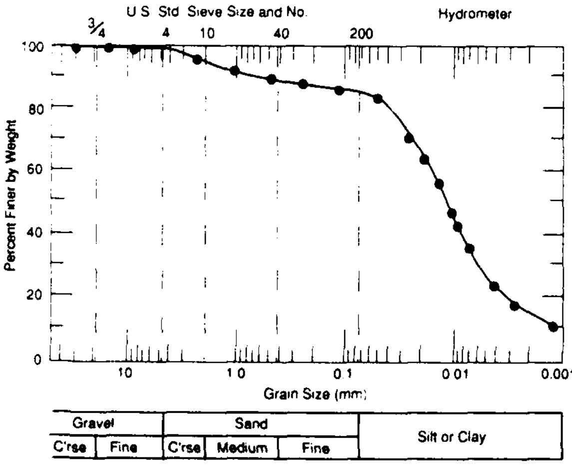


Figure A14. Grain size distribution—Nichols Road, subgrade at 7-ft depth, liquid limit = 21, plastic limit = 19, plasticity index = 2.

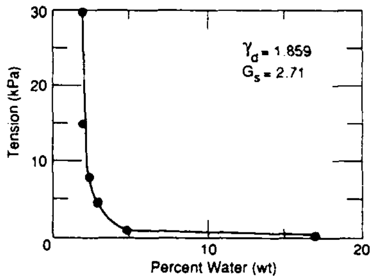


Figure A15. Moisture retention—Newton Field, sand subbase.

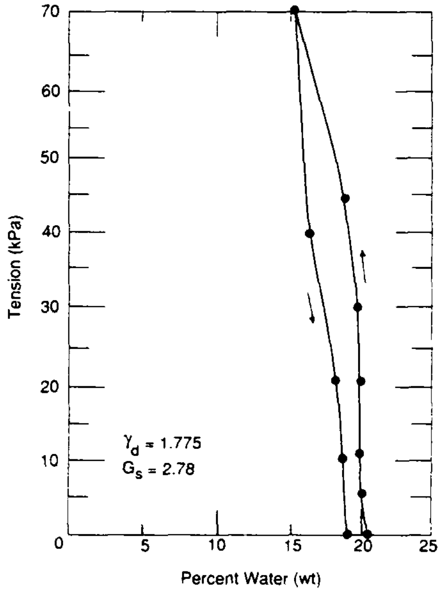


Figure A16. Moisture retention—Newton Field station 4+44, subgrade, liquid limit = 22, plastic limit = 21, plasticity index = 1.

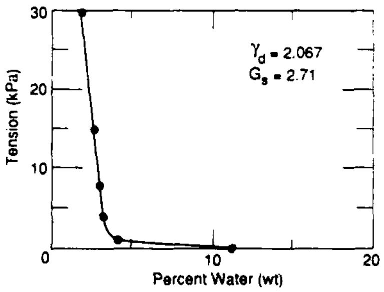


Figure A17. Moisture retention—Newton Field, gravel base course.

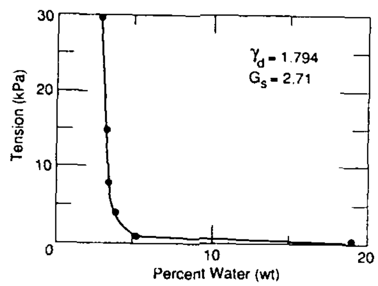


Figure A18. Moisture retention—Nichols Road, sand subbase.

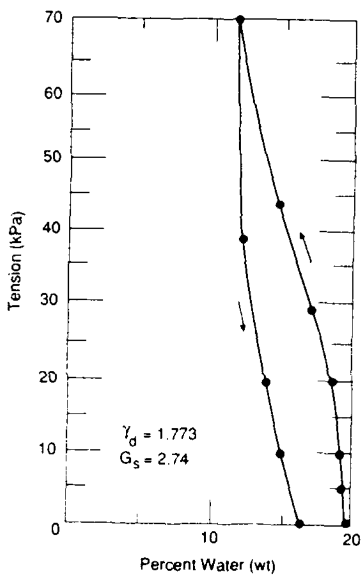


Figure A19. Moisture retention—Nichols Road, subgrade at 3-ft depth.

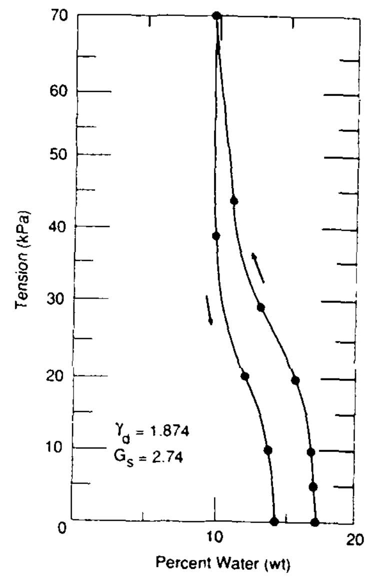


Figure A20. Moisture retention—Nichols Road, subgrade at 4-ft depth.

APPENDIX B: THERMOCOUPLE AND TENSIOMETER DATA RECORDED AT CMP, NEWTON FIELD AND NICHOLS ROAD, WINTER 1986—1987.

Table B1. Air temperatures (°F) CMP, Jackman, Maine.

Date	*Max °F*	*Min °F*	*Avg °F*	*FR Index °F-day*	*Date*	*Max °F*	*Min °F*	*Avg °F*	*FR Index °F-day*
23 Oct 86	52	35	43.5	-74.50	11 Feb 87	11	-3	4.0	-1523.00
24 Oct 86	57	29	45.0	-63.5	12 Feb 87	10	-12	-1.0	-1556.00
25 Oct 86	45	24	34.5	-61.00	13 Feb 87	12	-10	1.0	-1587.00
26 Oct 86	48	30	39.0	-54.00	14 Feb 87	-3	-20	-11.5	-1630.50
27 Oct 86	53	30	41.5	-44.50	15 Feb 87	-10	-22	-16.0	-1678.50
28 Oct 86	45	35	40.0	-36.50	16 Feb 87	0	-20	-10.0	-1720.50
29 Oct 86	49	37	43.0	-25.50	17 Feb 87	12	-18	-3.0	-1755.50
30 Oct 86	60	37	48.5	-9.00	18 Feb 87	21	-3	9.0	-1778.50
31 Oct 86	42	17	29.5	-11.50	19 Feb 87	23	0	11.5	-1799.00
01 Nov 86	38	20	29.0	-14.50	20 Feb 87	20	4	12.0	-1819.00
02 Nov 86	53	40	46.5	.00	21 Feb 87	28	6	17.0	-1834.00
03 Nov 86	38	15	26.5	-5.50	22 Feb 87	26	4	15.0	-1851.00
04 Nov 86	42	16	29.0	-8.50	23 Feb 87	30	0	15.0	-1868.00
05 Nov 86	37	11	24.0	-16.50	24 Feb 87	31	3	17.0	-1883.00
06 Nov 86	34	10	22.0	-26.50	25 Feb 87	31	9	20.0	-1895.00
07 Nov 86	37	21	29.0	-29.50	26 Feb 87	29	9	19.0	-1908.00
08 Nov 86	50	40	45.0	-16.50	27 Feb 87	30	16	23.0	-1917.00
09 Nov 86	50	40	45.0	-3.50	28 Feb 87	36	10	23.0	-1926.00
10 Nov 86	40	22	31.0	-4.50	01 Mar 87	40	7	23.5	-1934.50
11 Nov 86	30	22	26.0	-10.50	02 Mar 87	28	8	18.0	-1948.50
12 Nov 86	35	20	27.5	-15.00	03 Mar 87	26	7	16.5	-1964.00
13 Nov 86	39	20	29.5	-17.50	04 Mar 87	40	-25	7.5	-1988.50
14 Nov 86	30	3	16.5	-33.00	05 Mar 87	39	-19	10.0	-2010.50
15 Nov 86	26	6	16.0	-49.00	06 Mar 87	32	-12	10.0	-2032.50
16 Nov 86	22	12	17.0	-64.00	07 Mar 87	24	4	14.0	-2050.50
17 Nov 86	37	24	30.5	-65.50	08 Mar 87	38	25	31.5	-2051.00
18 Nov 86	40	25	32.5	-65.00	09 Mar 87	46	25	35.5	-2047.50
19 Nov 86	31	10	20.5	-76.50	10 Mar 87	27	-10	8.5	-2071.00
20 Nov 86	21	2	11.5	-97.00	11 Mar 87	15	-10	2.5	-2100.50
21 Nov 86	20	0	10.0	-119.00	12 Mar 87	28	-8	10.0	-2122.50
22 Nov 86	28	9	18.5	-132.50	13 Mar 87	38	10	24.0	-2130.50
23 Nov 86	34	19	26.5	-138.00	14 Mar 87	39	8	23.5	-2139.00
24 Nov 86	37	24	30.5	-139.50	15 Mar 87	41	-6	17.5	-2153.50
25 Nov 86	44	22	33.0	-138.50	16 Mar 87	37	16	26.5	-2159.00
26 Nov 86	32	11	21.5	-149.00	17 Mar 87	32	16	24.0	-2167.00
27 Nov 86	38	32	35.0	-146.00	18 Mar 87	29	18	23.5	-2175.50
28 Nov 86	41	32	36.5	-141.50	19 Mar 87	36	23	29.5	-2178.00
29 Nov 86	37	18	27.5	-146.00	20 Mar 87	32	25	28.5	-2181.50
30 Nov 86	42	23	32.5	-145.50	21 Mar 87	35	22	28.5	-2185.00
01 Dec 86	40	6	23.0	-154.50	22 Mar 87	38	32	35.0	-2182.00
02 Dec 86	35	-7	14.0	-172.50	23 Mar 87	52	25	38.5	-2175.50
03 Dec 86	36	14	25.0	-179.50	24 Mar 87	57	23	40.0	-2167.50
04 Dec 86	42	29	35.5	-176.00	25 Mar 87	61	22	41.5	-2158.00
05 Dec 86	38	26	32.0	-176.00	26 Mar 87	67	27	47.0	-2145.00
06 Dec 86	37	22	29.5	-178.50	27 Mar 87	48	30	39.0	-2136.00
07 Dec 86	20	10	15.0	-195.50	28 Mar 87	40	28	34.0	-2134.00
08 Dec 86	20	-5	7.5	-220.00	29 Mar 87	58	26	42.0	-2124.00
09 Dec 86	10	-15	-2.5	-254.50	30 Mar 87	58	24	41.0	-2115.00
10 Dec 86	23	-10	6.5	-280.00	31 Mar 87	56	30	43.0	-2104.00
11 Dec 86	33	10	21.5	-290.50	01 Apr 87	50	30	40.0	-2096.00
12 Dec 86	23	-8	7.5	-315.00	02 Apr 87	34	19	26.5	-2101.50
13 Dec 86	22	-6	8.0	-339.00	03 Apr 87	45	21	33.0	-2100.50
14 Dec 86	31	4	17.5	-353.50	04 Apr 87	47	27	37.0	-2095.50
15 Dec 86	32	-8	12.0	-373.50	05 Apr 87	45	34	39.5	-2088.00

Table B1. (cont'd). Air temperatures (°F) CMP, Jackman, Maine.

Date	Max °F	Min °F	Avg °F	FR Index °F-day	Date	Max °F	Min °F	Avg °F	FR Index °F-day
16 Dec 86	30	-3	13.5	-392.00	06 Apr 87	41	33	37.0	-2083.00
17 Dec 86	26	-9	8.5	-415.50	07 Apr 87	45	33	39.0	-2076.00
18 Dec 86	25	3	14.0	-433.50	08 Apr 87	30	30	34.5	-2073.50
19 Dec 86	30	19	24.5	-441.00	09 Apr 87	39	29	34.0	-2071.50
20 Dec 86	34	8	21.0	-452.00	10 Apr 87	45	24	34.5	-2069.00
21 Dec 86	34	3	18.5	-465.50	11 Apr 87	57	25	41.0	-2060.00
22 Dec 86	20	5	12.5	-485.00	12 Apr 87	61	28	44.5	-2047.50
23 Dec 86	32	8	20.0	-497.00	13 Apr 87	59	30	44.5	-2035.00
24 Dec 86	30	10	20.0	-509.00	14 Apr 87	51	17	34.0	-2033.00
25 Dec 86	34	26	30.0	-511.00	15 Apr 87	58	19	38.5	-2026.50
26 Dec 86	38	28	33.0	-510.00	16 Apr 87	57	27	42.0	-2016.50
27 Dec 86	30	0	15.0	-527.00	17 Apr 87	60	25	42.5	-2006.00
28 Dec 86	28	-12	8.0	-551.00	18 Apr 87	68	22	45.0	-1993.00
29 Dec 86	33	14	23.5	-559.50	19 Apr 87	70	37	53.5	-1971.50
30 Dec 86	35	22	28.5	-563.00	20 Apr 87	74	41	57.5	-1946.00
31 Dec 86	32	5	18.5	-576.50	21 Apr 87	76	40	58.0	-1920.00
01 Jan 87	24	-12	6.0	-602.50	22 Apr 87	77	32	54.5	-1897.50
02 Jan 87	31	10	20.5	-614.00	23 Apr 87	63	27	45.0	-1884.50
03 Jan 87	23	16	19.5	-626.50	24 Apr 87	56	30	43.0	-1875.50
04 Jan 87	20	6	13.0	-645.50	25 Apr 87	50	20	35.0	-1870.50
05 Jan 87	24	4	14.0	-663.50	26 Apr 87	56	18	37.0	-1865.50
06 Jan 87	24	6	15.0	-680.50	27 Apr 87	52	20	36.0	-1861.50
07 Jan 87	30	16	23.0	-689.50	28 Apr 87	56	22	39.0	-1854.50
08 Jan 87	30	9	19.5	-702.00	29 Apr 87	46	27	36.5	-1850.00
09 Jan 87	24	2	13.0	-721.00	30 Apr 87	40	27	33.5	-1848.50
10 Jan 87	20	2	11.0	-742.00	01 May 87	41	28	34.5	-1846.00
11 Jan 87	22	0	11.0	-763.00	02 May 87	50	16	33.0	-1845.00
12 Jan 87	25	10	17.5	-777.50	03 May 87	48	14	31.0	-1846.00
13 Jan 87	22	12	17.0	-792.50	04 May 87	53	19	36.0	-1842.00
14 Jan 87	24	10	17.0	-807.50	05 May 87	59	25	42.0	-1832.00
15 Jan 87	35	11	23.0	-816.50	06 May 87	52	30	41.0	-1823.00
16 Jan 87	32	7	19.5	-829.00	07 May 87	54	40	47.0	-1808.00
17 Jan 87	24	12	18.0	-843.00	08 May 87	55	22	38.5	-1801.50
18 Jan 87	6	-23	-8.5	-883.50	09 May 87	58	28	43.0	-1790.50
19 Jan 87	14	-6	4.0	-911.50	10 May 87	60	26	43.0	-1779.50
20 Jan 87	20	-12	4.0	-939.50	11 May 87	62	26	44.0	-1767.50
21 Jan 87	18	-2	-2.0	-973.50	12 May 87	60	30	45.0	-1754.50
22 Jan 87	23	-16	3.5	-1002.004	13 May 87	57	29	43.0	-1743.50
23 Jan 87	22	-5	8.5	-1025.504	14 May 87	65	30	47.5	-1728.00
24 Jan 87	3	-17	-7.0	-1064.504	15 May 87	73	36	54.5	-1705.50
25 Jan 87	0	-15	-7.5	-1104.004	16 May 87	55	34	44.5	-1693.00
26 Jan 87	0	-26	-13.0	-1149.004	17 May 87	60	28	44.0	-1681.00
27 Jan 87	13	-21	-4.0	-1185.004	18 May 87	66	38	52.0	-1661.00
28 Jan 87	18	-12	3.0	-1214.004	19 May 87	67	25	46.0	-1647.00
29 Jan 87	20	-8	6.0	-1240.004	20 May 87	64	26	45.0	-1634.00
30 Jan 87	18	-6	6.0	-1266.004	21 May 87	71	31	51.0	-1615.00
31 Jan 87	18	3	10.5	-1287.504	22 May 87	75	39	57.0	-1590.00
01 Feb 87	16	-2	7.0	-1312.504	23 May 87	73	39	56.0	-1566.00
02 Feb 87	22	-5	8.5	-1336.004	24 May 87	70	42	56.0	-1566.00
03 Feb 87	31	-5	13.0	-1355.004	25 May 87	65	36	50.5	-1523.50
04 Feb 87	25	16	20.5	-1366.504	26 May 87	72	40	56.0	-1499.50
05 Feb 87	22	-9	6.5	-1392.004	27 May 87	78	47	62.5	-1469.00
06 Feb 87	10	-8	1.0	-1423.004	28 May 87	69	53	61.0	-1440.00
07 Feb 87	20	-5	7.5	-1447.504	29 May 87	75	54	64.5	-1407.50
08 Feb 87	34	14	24.0	-1455.504	30 May 87	70	55	62.5	-86.00
09 Feb 87	22	10	16.0	-1471.504	31 May 87	75	58	66.5	-86.00
10 Feb 87	21	-4	8.5	-1495.004					

Table B2. Newton Field, Jackman, Maine RWY 14/32.

Thermocouple assembly at station 4+50 +/− subsurface temperatures (°F)

TC no. *Depth (in.)*	*1* *3.84*	*2* *4.92*	*3* *8.28*	*4* *12.60*	*5* *16.08*	*6* *16.59*	*7* *16.85*	*8* *17.10*	*9* *17.36*	*10* *17.61*	*11* *17.87*	*12* *18.12*
6 Oct 86	41.4	40.3	39.5	38.3	40.1	45.6	47.2	47.1	48.5	50.0	51.2	51.8
7 Oct 86	32.9	33.8	35.9	37.6	38.6	42.1	43.9	44.5	45.9	48.2	50.0	50.9
21 Oct 86	52.9	53.2	53.5	53.2	53.1	52.1	51.7	51.6	51.2	50.7	50.3	50.0
22 Oct 86	51.2	51.0	49.0	47.8	47.6	48.1	48.4	48.4	49.0	49.5	50.0	50.3
30 Oct 86	48.3	48.8	49.4	49.4	49.6	49.4	49.2	49.3	49.4	49.2	49.2	49.3
6 Nov 86	31.7	31.7	32.0	32.4	32.6	36.2	38.0	38.5	40.1	42.3	44.2	45.0
12 Nov 86	32.2	32.3	32.6	32.9	33.0	36.2	37.8	38.1	39.1	41.6	43.1	43.8
19 Nov 86	30.7	30.2	30.4	30.8	32.0	35.1	36.8	37.2	38.8	40.7	42.2	43.0
4 Dec 86	32.0	31.4	31.0	30.8	31.0	32.2	32.7	34.2	35.5	37.2	38.3	39.1
12 Dec 86	19.7	18.6	16.6	15.5	15.5	20.5	23.0	23.8	24.8	29.2	32.0	33.4
18 Dec 86	25.4	24.4	29.9	22.2	21.9	24.9	26.5	27.0	28.3	30.4	31.9	32.9
26 Dec 86	31.4	31.3	31.1	31.0	31.1	31.9	32.3	32.6	32.4	33.1	33.9	34.2
6 Jan 87	21.2	20.8	20.5	20.6	20.9	24.1	25.8	26.3	27.8	29.9	31.6	32.6
14 Jan 87	27.1	25.8	23.7	22.6	22.5	25.1	26.6	27.0	28.1	30.0	31.4	32.1
21 Jan 87	10.7	10.0	10.1	10.4	11.0	16.6	19.4	19.9	22.4	25.8	28.5	30.0
28 Jan 87	15.6	13.7	10.7	9.0	9.5	14.6	17.3	18.0	20.3	23.8	26.4	27.9
5 Feb 87	28.9	27.7	25.6	24.7	25.2	27.0	27.8	28.1	29.0	30.7	30.9	31.3
14 Feb 87	5.5	5.3	5.2	5.2	5.5	11.6	14.3	15.4	18.5	22.0	24.8	26.3
18 Feb 87	23.5	21.5	17.9	15.3	14.3	17.9	20.1	20.4	22.2	24.8	26.8	27.8
27 Feb 87	32.4	31.4	29.7	28.7	28.8	29.4	29.7	29.8	30.0	30.6	31.0	31.2
6 Mar 87	27.3	25.4	23.1	21.7	22.1	24.1	25.3	25.6	26.7	28.2	29.4	30.0
8 Mar 87	37.3	35.8	32.6	32.2	32.2	32.0	32.0	31.9	31.9	31.8	31.7	31.7
9 Mar 87	32.5	32.4	32.4	32.2	32.2	31.9	31.9	32.0	31.8	31.8	31.7	31.8
25 Mar 87	55.4	53.5	42.6	42.6	41.7	39.0	39.8	38.8	37.8	36.2	34.1	33.2
26 Mar 87	48.0	47.8	46.7	45.5	45.8	41.8	39.7	39.4	37.5	34.9	33.1	32.2
2 Apr 87	54.8	50.4	42.3	38.2	37.6	36.2	35.8	36.1	35.8	35.4	34.9	34.7
7 Apr 87	42.6	42.1	41.6	41.4	41.5	39.4	38.4	38.1	37.1	35.5	34.5	33.9
10 Apr 87	42.3	40.7	38.5	38.1	38.2	37.1	36.4	36.2	35.5	34.6	33.8	33.4
13 Apr 87	68.9	65.2	58.3	54.6	53.6	48.2	46.2	45.7	43.8	40.7	38.2	37.1
15 Apr 87	71.9	66.6	58.0	54.1	53.2	48.9	46.8	46.3	44.3	41.5	39.1	37.9
27 Apr 87	77.4	72.5	63.4	58.8	57.5	54.1	52.6	52.2	50.8	48.6	46.8	45.8
28 Apr 87	49.4	50.8	53.9	56.0	56.3	53.2	51.7	51.0	49.5	47.1	45.2	44.3
1 May 87	56.4	51.9	44.5	41.0	40.7	41.0	41.4	41.6	41.7	42.1	42.4	42.4
6 May 87	57.2	55.5	52.9	51.9	51.8	49.9	49.1	48.8	48.0	46.8	45.8	45.4
13 May 87	78.8	73.4	63.9	58.9	58.1	54.9	53.6	53.3	52.0	50.1	48.4	47.8
14 May 87	72.3	68.9	64.3	62.8	62.7	58.6	56.5	55.7	53.7	51.0	48.8	47.9

TC no. *Depth (in.)*	*13* *21.8*	*14* *23.3*	*15* *25.2*	*16* *26.8*	*17* *30.1*	*18* *36.1*	*19* *42.1*	*20* *54.1*	*21* *66.1*	*22* *78.1*	*23* *114.1*	*24* *138.12*
6 Oct 86	51.9	51.9	51.7	51.7	52.0	52.1	52.1	52.0	51.7	51.2	50.0	49.5
7 Oct 86	50.7	50.8	50.6	50.7	51.4	51.7	51.9	52.0	51.7	51.3	50.0	49.4
21 Oct 86	49.1	49.1	49.1	49.1	49.0	49.0	49.1	49.4	49.9	50.2	49.9	49.4
22 Oct 86	49.3	49.7	49.7	49.7	49.7	49.7	49.8	50.2	50.4	50.8	50.7	50.2
30 Oct 86	48.5	48.7	48.8	48.9	48.8	48.9	49.1	49.7	50.0	50.4	50.4	49.9
6 Nov 86	43.2	43.3	43.1	43.3	44.2	45.2	46.1	47.2	48.1	48.5	48.9	48.7
12 Nov 86	42.0	42.1	41.9	42.0	42.8	43.7	44.4	45.7	46.8	47.6	48.4	48.4
19 Nov 86	41.5	41.4	41.2	41.6	42.2	43.0	44.2	46.2	47.8	49.0	50.3	50.4
4 Dec 86	35.5	35.9	35.4	35.6	36.4	37.5	38.8	42.0	43.8	45.2	48.0	48.3
12 Dec 86	32.2	32.3	32.2	32.4	33.4	34.7	36.0	38.3	40.5	42.2	45.3	45.9
18 Dec 86	32.5	32.6	32.4	34.7	33.7	34.8	35.9	38.1	40.3	42.2	45.7	46.5
26 Dec 86	32.9	33.1	32.9	33.0	33.9	34.7	35.6	37.5	39.4	41.2	45.1	46.0
6 Jan 87	31.6	31.7	31.7	32.0	32.9	33.8	34.6	36.3	38.1	39.7	43.4	44.6
14 Jan 87	31.1	31.3	31.2	31.6	32.4	33.2	34.1	35.6	37.4	38.9	42.6	43.8
21 Jan 87	27.5	29.5	29.5	30.2	32.3	33.0	33.9	35.5	37.2	38.8	42.4	43.7
28 Jan 87	27.7	27.8	27.8	28.4	30.7	32.3	33.2	34.8	36.5	38.0	41.7	42.8
5 Feb 87	31.0	31.1	31.0	31.2	32.1	32.9	33.7	35.3	36.8	38.4	42.0	43.3
14 Feb 87	26.3	26.6	26.7	27.4	30.0	32.3	33.7	36.0	37.5	38.5	41.9	43.4
18 Feb 87	26.9	27.2	27.1	27.6	29.2	30.8	32.3	34.7	35.2	36.7	40.2	41.5

Table B2 (cont'd). Newton Field, Jackman, Maine RWY 14/32.

Thermocouple assembly at station 4+50 +/– subsurface temperatures (°F)

TC no.	13	14	15	16	17	18	19	20	21	22	23	24
Depth (in.)	21.8	23.3	25.2	26.8	30.1	36.1	42.1	54.1	66.1	78.1	114.1	138.12
27 Feb 87	30.8	30.9	30.9	31.0	31.3	31.9	32.5	33.8	35.2	36.5	40.1	41.1
6 Mar 87	29.6	29.7	29.8	30.0	31.0	32.1	32.6	33.9	35.1	36.4	39.7	40.8
8 Mar 87	30.7	30.7	30.7	30.8	31.0	31.4	32.0	33.2	34.4	35.7	39.1	40.3
9 Mar 87	31.2	30.9	30.8	31.0	31.1	31.6	32.2	33.5	34.6	36.7	40.1	41.0
25 Mar 87	31.0	31.0	30.9	31.0	31.1	31.4	32.0	33.2	34.6	36.1	39.1	39.9
26 Mar 87	32.0	32.0	31.9	31.9	31.8	31.9	32.3	33.2	34.4	35.5	38.8	39.9
2 Apr 87	33.1	33.1	33.3	33.4	33.3	33.4	33.9	34.9	36.2	37.3	40.1	40.6
7 Apr 87	32.9	32.7	33.1	32.9	32.5	32.6	32.9	33.9	34.9	36.1	39.0	40.2
10 Apr 87	32.4	32.6	33.1	33.5	33.2	33.4	33.8	34.6	35.5	36.5	39.1	39.8
13 Apr 87	33.6	33.4	34.2	34.2	32.3	32.3	32.9	33.9	35.0	36.2	39.1	40.1
15 Apr 87	35.4	35.2	36.2	36.4	34.4	33.6	34.0	35.0	35.9	36.8	39.3	39.7
27 Apr 87	45.0	45.2	45.6	45.6	45.0	43.9	42.8	41.1	39.5	38.8	39.4	40.1
28 Apr 87	45.2	45.0	45.3	45.0	43.7	42.1	40.7	38.8	37.4	36.6	37.5	38.3
1 May 87	42.1	42.3	42.2	42.3	42.4	42.3	41.8	40.6	39.7	38.9	39.0	39.5
6 May 87	46.3	46.2	46.4	46.3	45.5	44.5	43.5	42.0	40.8	40.1	39.7	40.1
13 May 87	47.9	48.1	48.5	48.8	48.1	47.1	46.0	44.2	42.4	41.4	40.2	40.4
14 May 87	50.4	50.7	51.0	50.9	49.4	47.7	46.0	44.0	42.2	41.2	40.0	40.1

Table B3. Nichols Road, Jackman, Maine, subsurface temperatures.

Thermocouple assembly at station 1+57 subsurface temperatures (°F)

TC no.	2	3	4	5	6	7	8	9	10	11	12
Depth (in.)	12	21	30	36	48	60	72	84	108	144	180
7 Oct 86	47.6	50.7	54.8	56.5	57.8	58.0	57.6	57.0	55.5	53.0	50.5
21 Oct 86	49.9	50.2	51.4	52.2	52.9	53.6	54.3	54.7	54.5	52.9	50.7
22 Oct 86	47.9	48.1	50.3	51.2	52.3	52.9	53.5	54.0	54.1	52.6	50.6
30 Oct 86	50.0	49.9	50.0	50.0	50.5	51.3	52.3	52.9	53.4	52.6	50.8
6 Nov 86	33.9	37.3	41.7	44.0	47.0	49.1	50.5	51.4	52.3	51.9	50.4
12 Nov 86	34.9	36.4	39.7	41.7	44.3	46.5	48.1	49.3	51.0	51.2	50.2
19 Nov 86	32.2	34.2	36.9	38.7	41.3	43.5	45.8	47.6	49.8	51.0	50.4
4 Dec 86	31.7	32.1	33.6	35.3	37.9	40.4	42.4	44.2	47.2	49.7	50.2
12 Dec 86	25.5	27.8	31.9	34.8	37.8	40.3	42.2	43.9	47.1	50.1	50.8
18 Dec 86	25.6	26.4	29.7	32.2	35.1	37.3	39.4	41.4	44.6	48.0	49.2
26 Dec 86	31.0	31.0	31.9	32.8	34.9	36.7	38.5	40.3	43.5	47.1	49.0
6 Jan 87	23.1	25.1	28.9	31.4	33.9	35.5	37.2	38.8	42.0	45.6	47.8
14 Jan 87	24.5	25.9	29.1	30.9	33.1	34.7	36.2	37.7	40.6	44.2	46.5
21 Jan 87	14.8	17.9	24.4	28.3	32.6	34.2	36.0	37.5	40.4	43.9	46.4
28 Jan 87	13.4	15.4	21.6	25.7	31.2	33.9	35.6	37.1	40.1	43.7	46.2
5 Feb 87	27.1	28.4	29.8	30.9	32.9	34.5	36.2	37.8	40.5	44.4	46.8
14 Feb 87	10.5	13.9	20.5	25.5	31.5	35.0	37.0	38.5	41.0	44.0	46.3
18 Feb 87	20.2	18.8	21.8	24.6	28.7	31.9	33.6	34.8	37.5	41.1	43.8
19 Feb 87	14.3	18.6	22.8	25.4	29.2	32.4	34.3	35.4	38.4	42.0	44.7
24 Feb 87	26.9	26.3	27.4	28.4	30.3	31.9	33.6	34.9	37.5	41.0	43.6
27 Feb 87	29.2	28.1	29.7	29.2	30.1	31.3	32.6	34.1	36.9	40.7	43.5
6 Mar 87	27.0	25.7	27.0	28.4	28.2	31.9	33.3	34.6	37.1	40.7	43.5
9 Mar 87	32.3	31.7	30.9	30.7	31.0	31.9	33.2	34.4	36.9	40.5	43.2
20 Mar 87	31.6	31.2	31.3	31.4	31.7	32.1	33.0	34.2	36.5	39.9	42.6
26 Mar 87	44.4	40.5	35.1	32.4	32.2	32.3	33.0	34.1	36.5	39.9	42.6
2 Apr 87	36.5	33.3	32.3	31.1	30.1	29.9	30.5	31.7	34.2	37.8	41.2
6 Apr 87	41.2	38.4	35.4	33.7	32.3	32.3	33.0	34.0	36.1	39.1	41.7
10 Apr 87	35.0	35.5	34.8	33.6	32.2	32.4	33.0	34.1	36.2	39.4	42.0
13 Apr 87	54.3	46.3	40.4	37.3	32.6	32.3	32.9	33.1	35.5	38.0	40.7
15 Apr 87	49.9	43.7	39.6	36.4	31.4	30.6	31.3	32.6	34.9	38.2	41.2

Table B3 (cont'd).

Thermocouple assembly at station 1+57 subsurface temperatures (°F)

TC no.	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Depth (in.)	*12*	*21*	*30*	*36*	*48*	*60*	*72*	*84*	*108*	*144*	*180*
27 Apr 87	55.1	48.5	44.9	42.4	38.1	35.0	33.4	33.5	35.1	38.2	41.2
28 Apr 87	49.2	50.4	47.8	44.8	40.5	37.5	35.5	35.0	35.8	38.6	41.0
28 Apr 87	48.9	50.1	47.5	44.5	40.2	37.1	35.2	34.6	35.4	38.1	40.7
28 Apr 87	48.9	50.1	47.5	44.5	40.3	37.2	35.3	34.7	35.5	38.1	40.7
1 May 87	44.4	41.0	40.7	40.4	39.2	37.6	36.2	35.5	35.5	38.1	40.8
6 May 87	50.0	48.5	47.2	45.9	43.3	41.0	39.3	38.1	37.5	38.8	41.0
13 May 87	59.3	52.6	49.9	48.2	45.1	42.2	40.0	38.8	37.5	38.2	40.4

Table B4. Tensiometer data, Newton Field, Jackman, Maine.

	Tensiometer depth (ft)				
Date	*1* *psi*	*1.5* *psi*	*2* *psi*	*3* *psi*	*Waterwell depth (in.)*
7 Oct 86	0.0	0.0	0.0	0.0	
21 Oct 86	0.0	0.0	0.1	0.3	
22 Oct 86	0.3	0.4	0.6	0.7	100.0
30 Oct 86	0.0	0.0	0.0	0.3	101.0
6 Nov 86	0.0	0.0	0.0	0.4	101.0
12 Nov 86	0.0	0.0	0.1	0.4	99.0
19 Nov 86	0.0	0.0	0.1	0.6	106.0
4 Dec 86	0.0	0.0	0.4	1.0	104.5
12 Dec 86	0.0	0.0	0.3	1.0	118.0
18 Dec 86	0.0	0.0	0.3	1.2	134.0
26 Dec 86	0.0	0.0	0.6	1.5	148.0
6 Jan 87	0.0	0.3	0.6	1.8	147.5
14 Jan 87	0.9	1.0	1.3	2.4	148.0
21 Jan 87	1.2	1.3	1.8	2.6	147.0
28 Jan 87	7.4	6.8	5.0	4.6	148.0
5 Feb 87	6.5	6.2	5.1	5.0	146.0
14 Feb 87	9.7	8.7	5.6	5.4	148.0
18 Feb 87	10.1	9.1	6.1	5.7	147.5
27 Feb 87	9.4	8.8	6.8	6.3	147.0
6 Mar 87	7.6	7.4	6.0	5.9	149.0
8 Mar 87					—
9 Mar 87	6.9	6.8	5.9	5.7	—
25 Mar 87	0.0	0.0	0.6	1.8	41.5
26 Mar 87					42.0
2 Apr 87		Housing box flooded			147.0
7 Apr 87					131.0
10 Apr 87					127.0
13 Apr 87	15.4	0.0	0.3	1.2	—
15 Apr 87	0.0	0.0	0.3	0.9	125.0
27 Apr 87					112.0
28 Apr 87					
1 May 87		Housing box flooded			108.0
6 May 87					98.0
13 May 87					105.0
14 May 87					

Table B5. Tensiometer data, Nichols Road, Jackman, Maine.

	Tensiometer depths (ft)			
Date	*2* *psi*	*3* *psi*	*4* *psi*	*Waterwell depth (in.)*
7 Oct 86	0.00	-0.29	-0.29	
21 Oct 86	0.15	0.07	0.00	63
22 Oct 86	0.29	0.00	0.00	65
30 Oct 86	0.15	0.00	0.00	60
6 Nov 86	0.00	0.00	0.00	66
12 Nov 86	0.00	0.00	0.00	59
19 Nov 86	0.15	0.00	0.00	67
4 Dec 86	1.32			58
12 Dec 86	7.06	0.80	1.18	69
18 Dec 86	9.26	2.35	2.50	79
26 Dec 86	3.23	0.00	2.06	84
6 Jan 87	5.53	0.00	2.94	89
14 Jan 86	6.17	0.00	3.35	96
21 Jan 87				103
28 Jan 87				97
5 Feb 87				96
14 Feb 87				96
18 Feb 87	7.35	0.00	5.59	97
24 Feb 87	6.76	0.00	8.67	—
27 Feb 87	6.17	0.00	8.67	98
6 Mar 87	0.74		7.64	97
9 Mar 87	0.29	0.00	8.82	—
20 Mar 87	0.00	0.00	6.91	—
26 Mar 87	0.00	0.00	0.88	65
2 Apr 87	0.00	0.00	1.32	49
6 Apr 87				41
10 Apr 87	0.00	0.00	0.00	37
13 Apr 87	0.00	0.00		—
15 Apr 87	0.00	0.00	0.00	38
27 Apr 87				48
1 May 87				42
6 May 87				43
13 May 87				46

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In 1986, Newton Field, a small runway in Jackman, Maine, was reconstructed using a 2-in.-thick layer of extruded polystyrene insulation. At the same time, Nichols Road, a nearby town road, was reconstructed to a conventional, uninsulated cross section. Both Newton Field and Nichols Road were similarly monitored: thermocouples, tensiometers, and groundwater wells were installed during construction, and, following construction, a pavement surface elevation grid was established at each of the test sites for monitoring frost heave. This report discusses the performance of the insulated and uninsulated pavements during the first of four winters of observation.

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